BYJU'S EXAM PREP

Mechanical Engineering

Manufacturing and Engineering Materials

Short Notes

IMPORTANT FORMULAS TO REMEMBER

CHAPTER 1: METAL CASTING

CASTING

Casting is a process in which the liquid molten metal is poured into the mould cavity whose shape is same as that of the casting to be produced, allow it to solidify and after solidification the casting can be taken out by breaking the mould.

Steps involved in casting:

(i). Preparation of pattern.

(ii). Preparation of mould.

(iii). The Gating system (Design)

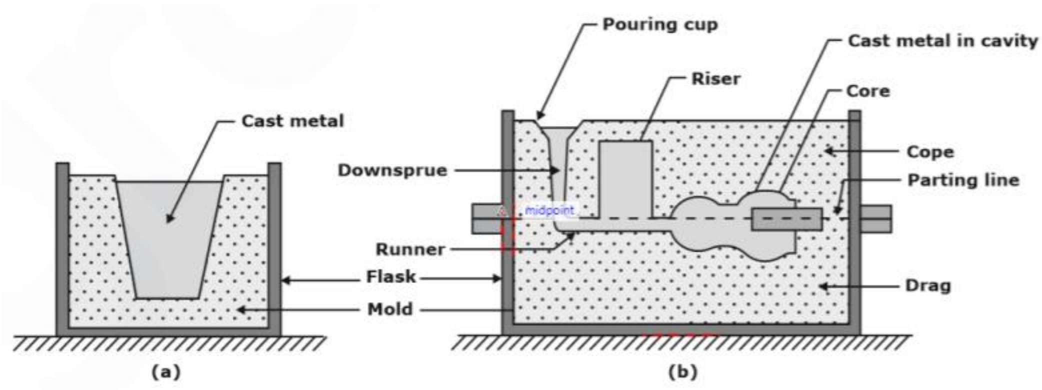
(iv). Design of Riser

(v). Melt the Metal

(vi). Pouring of molten metal

(vii). Solidification

(ix). Fettling, Finishing, Testing.



Pattern and mould:

A Pattern is the replica of the part to be cast (to be produced) and is used to prepare the mould cavity. Patterns are made of either wood or metal.

A Mould is an assembly of two or more metal blocks, or bonded refractory particles (sand) consisting of a primary cavity.

Pattern making: Pattern size = casting size ± allowances

Allowances:

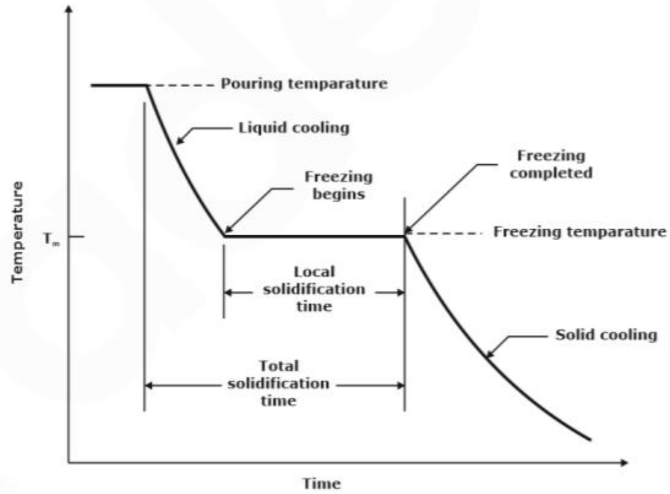
Shrinkage Allowance:

Shrinkage allowance is a positive allowance which is provided to take care of the contractions of a casting. The total contraction of a casting takes place in three stages:

Liquid Shrinkage: It is the shrinkage of molten metal when it cools from pouring temperature to freezing temperature and phase of molten metal remains liquid.

Solidification Shrinkage: It is the shrinkage of molten metal when the phase of the molten metal changes from liquid to solid.

Solid Shrinkage: It is the Shrinkage associated when the temperature of solid casting changes from freezing temperature to room temperature.



Note:

(i). The first two will be taken care by providing riser during casting. But the third will be provided as a shrinkage allowance in the pattern (taking place during the cooling of the material from freezing temp to room temp as a solid).

Solid shrinkage allowance for different materials:

Metals	Solid shrinkage in mm (per 1000mm)
Invar, Bismuth	0
White Metal	5
Cast iron	10
Aluminium	13
Copper	17
Steel	20
Brass	23

Machining Allowance: It is provided to take care of the machining to produce good surface finish is called the machining allowance.

Draft Allowance: It is provided to withdraw the pattern from the cavity without the damage. In general, 5° to 8° draft is given for internal surfaces and ½° and 2° is given for external surfaces.

Rapping allowance or Shake allowance: It is rapped all around the vertical faces to enlarge the mould cavity slightly which facilitates its ***easy removal***. It is ***a negative allowance*** and is to be applied only to those dimensions which are parallel to the parting plane.

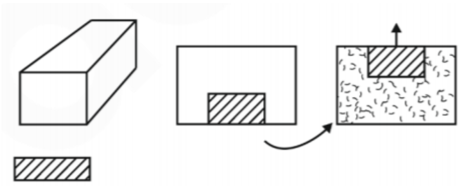
Note: If the pattern is made by using the materials like wax, mercury, polystyrene as pattern material, no shake allowance is provided.

Distortion Allowance: "To avoid the distortion, the shape of pattern itself should be given a distortion of equal amount in the opposite direction of the likely distortion direction so that final product will come in true shape known as distortion allowance"

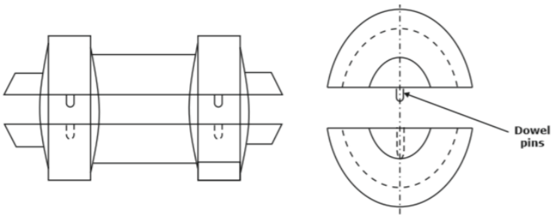
Types of patterns:

Solid or single piece pattern:

solid pattern placed in the drag position and it is used for making a flat surface like as gear blanks, square blocks etc.



Split pattern: It is widely used type of pattern for intricate castings.



Match plate patterns: The match plate is accurately placed between the cope and the drag flasks by means of locating pins. Production efficiency and dimensional accuracy is improved by this method.

Gated pattern: The parting line should he chosen so as the smallest portion of the pattern in the cope.

Sweep pattern: Sweep patten is used to generate surfaces of revolution in large castings which are axi-symmetrical or prismatic in nature such as bell shaped or cylindrical.

Skeleton pattern: This type of pattern is useful generally for very large castings required in small quantities.

Loose piece patterns: In it overhanging parts are fastened loosely to the main part of the pattern by wires or wooden pins and pattern cannot be removed in any direction.

Follow board pattern: It is used for those castings where there are some portions which are structurally weak and if not supported properly are likely to break under the force of ramming.

Mould making:

Types of sands:

Green sand: a mixture of sand, clay, water, and some organic additives, e.g., wood flour, dextrin, and sea coal.

Composition: 70-85% sand, 10-20% clay, 3 – 6% water, and 1-6% additives.

Dry sand: Silica sand + clay +sodium silicate.

Loam sand: Green or dry sand with at least 50% clay and dries hard. It also contains fire clay. It has 18 to 20% moisture and produces good surface finish.

Baking sand: It consists of refractory material and it is made of used sand or burnt sand.

Facing sand: Carboneous material sprinkled on the inner surfaces of the moulding cavity for obtaining better surface finish

CO_2 sand: In this sand in place of clay if sodium silicate is used, called as CO_2 sand.

Additives (up to 2% each):

(i). Cereal binder up to 2% increases the strength.

(ii). By-product in coke making up to 3% would improve the hot strength.

(iii). Saw dust: up to 2% improves the collapsibility by slowly burning and increase the permeability.

(iv). Starch or dextrin: Used for increasing strength and resistance for deformation of moulding sand.

(v). Coal Dust: It is basically used for providing better surface finish to the castings.

Properties of moulding sand:

Permeability and Permeability number: "Permeability is the ability of moulding sand to allow the air to escape". Permeability test is used for determining the Porosity property of moulding sand is denoted by:

$$\boxed{P_n = \frac{V.H}{P.A.T}}$$

As per the American foundry society (AFS) standard or ASTM standard, the standard test conditions are

D = H = 5.08 cm = 2inch

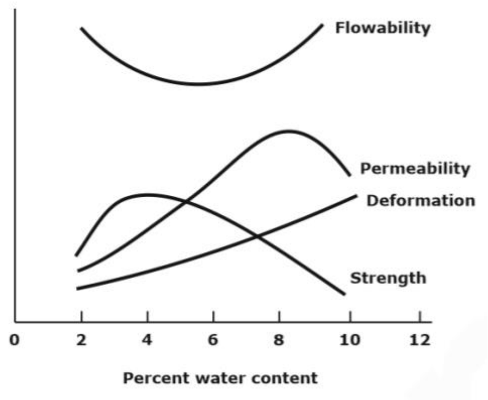
$P_n = 50.127/T$

Green strength: The optimum moisture content in the moulding sand is 7-8% and strength are such a condition is called the green strength of the sand.

Refractoriness: The ability of withstanding higher temperature of the molten metal without losing its strength and hardness is called refractoriness.

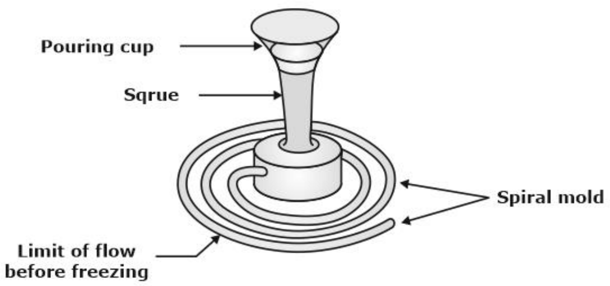
Collapsibility: It is the property of material due to which, it does not provide any resistance during the contraction of the solidified casting.

Flowability: The ability of flowing of moulding sand into each and every corner of the mould is called flowability.



Effect of moisture content on different properties

Fluidity: It depends on the Viscosity, solidification pattern of the alloy, Degree of super heat.



Spiral fluidity test

Properties increases ↑	Effect on Fluidity
Pouring temperature	↑
Surface finish of the mould	↑
Viscosity	↓
Density	↓
Surface tension	↓
Moisture content	↓

Machine moulding:

Jolting: Sand filled mould is raised to certain amount of height and it is allowed to fall freely on to the ground so that the reaction load produced by the ground will be used for ramming. The resulting impact forces the ***sand to get compacted uniformly*** into the mould. This type of ramming is suitable for horizontal surfaces.

Squeezing: A plate ***slightly smaller than the inside dimensions of the moulding flask*** is fitted into the flask already filled with the moulding sand and a uniform pressure is applied on the plate by either moving it down or by moving the flask upwards. The resulting force compacts the sand uniformly. ***The sand next to the plate rams hardest*** while the sand below is progressively less hard. This type is ***suitable for small castings and is generally suitable for shallow flasks.***

Sand slinging (combination of jolt squeezing machines) is done by throwing sand into the flask rapidly and with great force. This process develops uniformly high mould hardness. The process is very fast and gives high uniform sand ramming.

Core making: Core is used for making cavities and hollow projections and cores are normally made by CO_2 moulding.

Recess provided in the mould ***for locating, positioning, and supporting of cores*** is called core print.

Buoyancy force: $F_b = Vg\rho$

Net buoyancy force acting on the core = Weight of liquid displaced due to projected portion — total weight of core

$$\boxed{F = \rho_m Vg - \rho Vg = Vg(\rho_m - \rho)} \quad \text{(For Horizontal cores)}$$

Where:

ρ_m = density of molten metal

ρ = density of core material

V = volume of core

$$\boxed{F = \frac{\pi}{4}(D_1^2 - D^2)H\rho_m - V\rho} \quad \text{(For Vertical cores)}$$

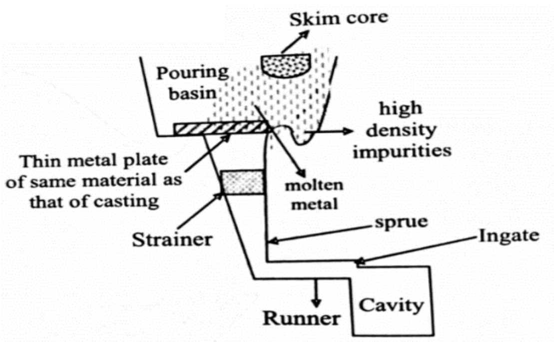
Where, V= total volume of the core in the mould.

The basic ***function of chaplet is to act as an additional support*** for supporting the unsupported length of the core.

Chill: The use of chill is used to get the ***directional solidification.*** The paddings are used to avoid the sand erosion taking place during sharp edged casting.

Gating system:

Elements: Pouring basin, Sprue, Runner, Ingate

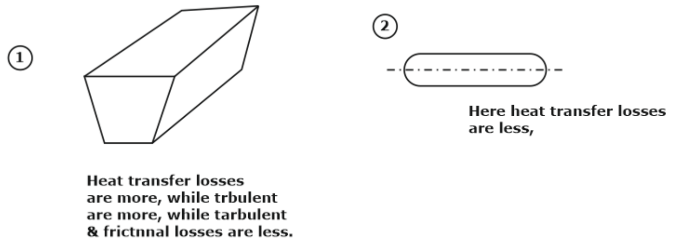


Strainer: acting as filter for separating the impurities present in molten metal.

Skim Bob: a semi-circular cut in a horizontal gate to prevent heavier and lighter impurities from entering the mould.

Splash core: reduces the eroding force of the liquid metal stream and also ensures settle down of high-density impurities.

Runner: Always horizontal with uniform trapezoidal cross-section and mainly used for minimizing the sand erosion in casting process.



Gating ratio: The gating ratio refer to the proportion of the cross-sectional areas between the sprue, runner, and in-gates, and is generally denoted as sprue area, runner area, and ingate area.

Gating ratio = A_S: A_R: A_G

Where: A_S = sprue area, A_R = runner area and A_G = ingate area.

Types:

Non pressurized gating system: If pressure above molten metal in gating system is equal to atmospheric pressure, it is called as non-pressurized gating system, i.e. P = P_{atm}.

Choke area is at the sprue base i.e. sprue base area is minimum in un-pressurized gating system i.e. 1:2:2, 1:4:4, 1:2:4, 0.5:1.5:1.

Due to low turbulence oxides formation will not takes place thus we can *cast Non-Ferrous alloys such as aluminium and magnesium alloys.*

Pressurized gating system: If top of the pouring basin is closed and the pressure above molten metal in pouring basin is maintained greater than atmospheric pressure is called as pressurized gating system, i.e. P > P_{atm}.

Choke area is at the ingate i.e. ingate area is minimum in pressurized gating system i.e. 4:2:1, 2:2:1, 2:1:0.5.

It is ***used for Ferrous castings.***

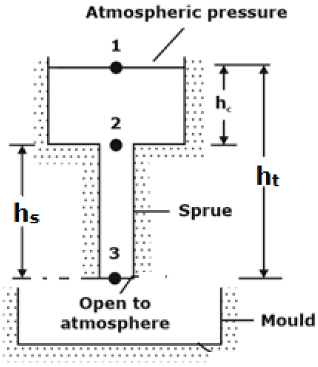
Top Gating System:

$$\text{Pouring time} = \frac{\text{Volume}}{\text{Flow rate}} = \frac{\text{Volume}}{A_c \times V_{max}}$$

$$\boxed{V_{max} = \sqrt{2gh_t}}$$

A_c= Choke area = $Min\left(A_s, A_r, A_g\right)$

Volume = Volume of the casting or pattern



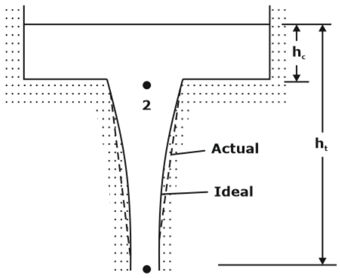
Mould Filling time: $\boxed{t_f = \frac{A_m \times h_m}{A_g \times \sqrt{2gh_t}}}$

To avoid air Aspiration:

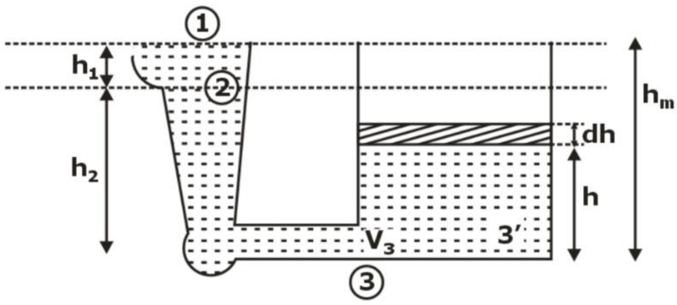
$$\Rightarrow \boxed{\frac{A_2}{A_3} = \frac{\sqrt{h_t}}{\sqrt{h_c}}}$$

$$A \propto \frac{1}{\sqrt{h}}$$

Thus, ideally, the sprue profile parabolic as shown by the solid lines in the Fig. but it is difficult to design thus, a straight tapered sprue (shown by the dashed lines) is preferred.



Bottom Gating System:



Mould Filling time: $\boxed{t_f = 2\frac{A_m}{A_g}\frac{1}{\sqrt{2g}}\left[\sqrt{h_t} - \sqrt{h_t - h_m}\right]}$

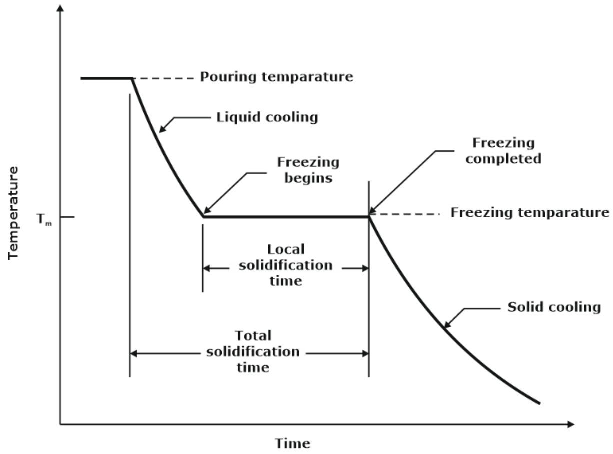
If height of the mould(h_m) is equal to total height (h_t):

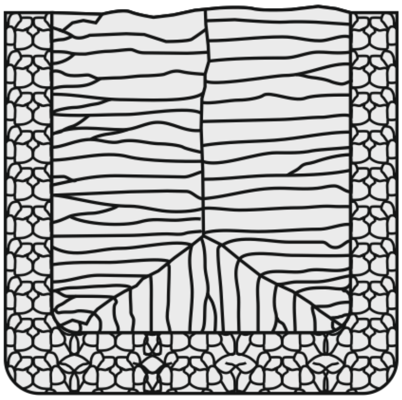
$$t_f = 2\frac{V_m}{A_g\sqrt{2gh_t}}$$

$$\boxed{(t_f)_{Bottom} = 2 \times (t_f)_{Top}}$$

Cooling and solidification time:

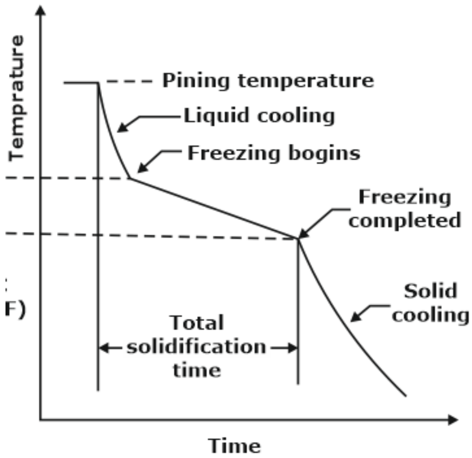
Pure metals: A pure metal solidifies at a constant temperature equal to its freezing point, which is the same as its melting point.



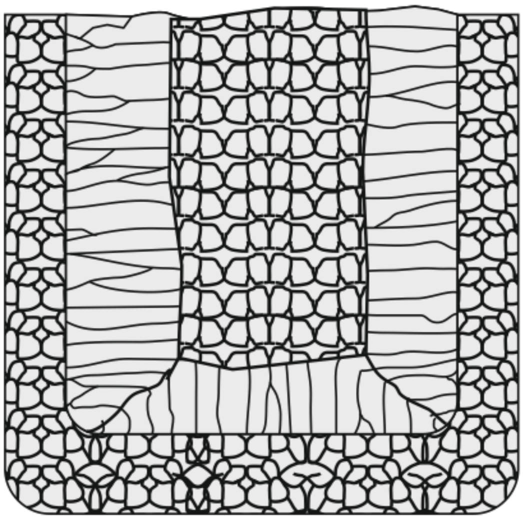


As the solidification starts on the mould wall and is rapidly cooled by the extraction of heat through the mould wall resulting in the fine and randomly oriented grains while coarse, columnar grains aligned toward the centre of the casting.

Alloys:



(b)



The start of freezing is like that of the pure metal. The solid portions are the dendrite structures that have formed sufficiently to trap small islands of liquid metal in the matrix and a mushy zone at the centre. As freezing continues and the dendrites grow, there develops an ***imbalance in composition between the metal that has solidified and the remaining molten metal.*** This composition imbalance is finally manifested in the completed casting in the form of ***segregation of the elements.***

Solidification time: "Solidification time is the time required for the casting to solidify after pouring". This time is dependent on the size and shape of the casting by an empirical relationship known as Chvorinov's rule, which states:

$$\boxed{t_S = k\left(\frac{V}{SA}\right)^n}$$

Where,

t_s = total solidification time

k = mould constant (or) solidification factor

V = volume of the casting,

SA = surface area of the casting,

n is an exponent usually taken to have a value = 2

$$\boxed{t_S = k\left(\frac{V}{SA}\right)^2}$$

$$\boxed{\text{Modulus (M)} = \frac{V}{SA} = \frac{\text{Volume of casting}}{\text{Surface area}}}$$

$$t_S = k(M)^2$$

$$T_S \propto \left(\frac{V}{SA}\right)^2$$

Riser design:

Condition to Design the Riser

1. $V_R \geq 3V_{Sc}$ ... [Necessary condition] i.e. Volume of riser should be at least 3 times the shrinkage volume of castings.

2. $T_{S_{Riser}} \geq T_{S_{cavity}}$ [Sufficient condition] The solidification time of molten metal in the riser must be at least equal to the solidification time of molten metal in the casting cavity.

Types of Riser:

Side Riser: $\boxed{SA = 2\left(\frac{\pi}{4}d^2\right) + \pi dh}$

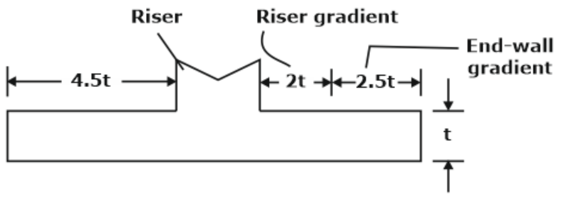
Top Riser: $\boxed{SA = \left(\frac{\pi}{4}d^2\right) + \pi dh}$

Optimum condition to get minimum surface area or **maximum solidification time in case of cylindrical riser:**

Side Riser	h = d	$\left(\frac{A}{V}\right) = \frac{6}{d}$
Top Riser	h =d/2	$\left(\frac{A}{V}\right) = \frac{6}{d}$

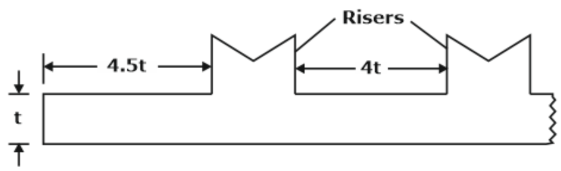
Location of risers:

One central riser is satisfactory if the maximum feeding distance is less than 4.5 times the plate thickness. The feeding distance should be measured from the edge of the riser.



(a) Plate with one central riser

It should be noted that, of the total distance 4.5t the riser gradient prevails up to a distance 2t, whereas the end wall gradient prevails in the remaining distance 2.5t. Thus, the maximum distance between the edges of two consecutive risers is 4t and not 9t.



(b) Maximum distance between two consecutive risers

Caine's Method

$$\boxed{\text{Freezing ratio : } X = \frac{\left(V/A_s\right)_{riser}}{\left(V/A_s\right)_{casting}} = \frac{M_{riser}}{M_{casting}}}$$

Freezing ratio, $X = \dfrac{a}{y-b} - c$

y = volumetric ratio $= \dfrac{V_r}{V_c}$

$$\boxed{\frac{M_r}{M_c} = \frac{a}{\left(\frac{V_r}{V_c}\right) - b}}$$

Modulus value for different type of risers:

Type of Riser	Modulus value
Spherical Riser	$M = \frac{R}{3} = \frac{D}{6}$
Top Cylindrical riser	$M = \frac{Dh}{D+4h} = \frac{D}{6}$

side cylindrical riser	$M = \frac{Dh}{2D+4h} = \frac{D}{6}$

Modulus Method:

Riser Solidification time: $\boxed{t_r \geq t_C}$

and $\boxed{M_r = 1.2M_C}$

Chvorinov's Law: $\boxed{t_s = k\left(\frac{V}{A_s}\right)^2}$

Shape factor (SF):

$\boxed{shape\ \ factor(S.F) = \frac{L+W}{t}}$

For Plate (L × w × t): $\boxed{SF = \frac{L+w}{t}}$

For Cube (a × a × a): $\boxed{SF = \frac{a+a}{a} = 2}$

For Sphere (of Diameter D): $\boxed{SF = \frac{D+D}{D} = 2}$

For Solid cylinder (Diameter D and Height H): $\boxed{SF = \frac{D+H}{D}}$

For thin cylinder: $\boxed{SF = \frac{L + \frac{\pi}{2}(D_o + D_i)}{\frac{(D_o - D_i)}{2}}}$

Special casting processes:

Expendable mould casting processes:

1. Shell moulding: The mould is a thin shell (typically 9 mm) made of sand held together by a ***thermosetting resin binder*** and the thickness of the shell can be determined accurately by controlling the time that the pattern is in contact with the mould.

It can be mechanized for mass production and is very economical for large quantities.

Applications: high precision parts such as gear housings, cylinder heads, and connecting rods.

2. Vacuum Moulding: It is also called the V-process uses a sand mould held together by vacuum pressure.

Applications: It is suitable particularly for thin walled (0.75 mm) complex shapes with uniform properties. Typical parts made are superalloy gas-turbine components with walls as thin as 0.5 mm.

3. Expanded Polystyrene process: also known as Evaporative-pattern and investment casting.

Applications: Typical applications are cylinder heads, engine blocks, crankshafts, brake components, manifolds, and machine bases. It is applied to mass produce castings for automobiles engines.

4. Investment casting: a pattern made of wax is coated with a refractory material to make the mould. The parts of great complexity and intricacy can be cast and close dimensional control—tolerances of ±0.075 mm, are possible.

Applications: All types of metals including steels, stainless steels, and other high temperature alloys, can be investment cast. Examples of parts include complex machinery parts, blades. and other components for turbine engines, Jewellery, and dental fixtures.

5. Plaster mould casting:

Mould is made of plaster of Paris (gypsum: $CaSO_4.2H_2O$) instead of sand.

Additives such as talc and silica flour arc mixed with the plaster to control contraction and setting time, reduce cracking, and increase strength. It is the casting of lower-melting-point alloys such as aluminium, magnesium. and some copper-base alloys.

6. Ceramic-mould casting:

Mould is made of refractory ceramic materials that can withstand higher temperatures than plaster.

It is used to cast steels, cast irons, and other high-temperature alloys. Its applications (relatively intricate parts) are like those of plaster mould casting except for the metals cast.

Permanent-Mould Casting Processes:

It uses reusable metal moulds.

Metals commonly cast in permanent moulds include aluminium, magnesium, copper-base alloys, and cast iron. The very high pouring temperatures of steel make permanent moulds unsuitable for this metal unless the mould is made of refractory material.

Permanent-mould casting include good surface finish and close dimensional control, as previously indicated.

More rapid solidification caused by the metal mould results in a finer grain structure, so stronger castings are produced.

Typical parts include automotive pistons. pump bodies, and certain castings for aircraft and missiles.

Variations of Permanent mould casting:

1. Slush casting: The flow of metal into the mould cavity is caused by gravity. Slush casting is used to make hollow parts such as statues, lamp pedestals, and toys out of low-melting-point metals such as zinc and tin.

2. Low pressure casting:

The liquid metal is forced into the cavity under low pressure— approximately 0.1 MPa from beneath so that the flow is upward.

3. Vacuum Permanent-Mould Casting:

Low-pressure casting operation where reduced air pressure from the vacuum in the mould is used to draw the liquid metal into the cavity, rather than forcing it.

4. Die Casting:

Die casting is a permanent-mould casting process in which the molten metal is injected into the mould cavity under high pressure ranging from 7 to 350 MPa.

There are two main types of die-casting machines:

(a). Hot chambers die casting:

Typical injection pressures: 7 to 35 MPa.

Limited in its applications ***to low-melting-point metals*** that do not chemically attack the plunger and other mechanical components. The metals include ***zinc, tin, lead, and sometimes magnesium.***

(b). Cold chambers die casting:

Injection pressures: typically, 14 to 140 MPa.

Typically used for casting aluminium, brass, and magnesium alloys.

Centrifugal casting:

True Centrifugal Casting:

The parts made by this process include pipes, tubes, bushings, and rings.

G-factor GF is the ratio of centrifugal force divided by weight:

$$\boxed{GF = \frac{F}{W} = \frac{mv^2}{Rmg} = \frac{v^2}{Rg}}$$

$$\boxed{N = \frac{30}{\pi}\sqrt{\frac{gGF}{R}} = \frac{30}{\pi}\sqrt{\frac{2gGF}{D}}}$$

GF = 60 to 80 are found to be appropriates for horizontal centrifugal casting.

For Vertical casting:

$$\boxed{N = \frac{30}{\pi}\sqrt{\frac{2gL}{R_t^2 - R_b^2}}}$$

Where L = vertical length of the casting (in m), R_t = inside radius at the top of the casting (in m) and R_b = inside radius at the bottom of the casting (in m).

Semi centrifugal castings:

It is used to produce solid castings rather than hollow castings.

G factors of around 15 are obtained.

Wheels and pulleys are examples of castings that can be made by this process.

Centrifuge casting:

The mould is designed with part cavities located away from the axis of rotation.

CHAPTER 2: ENGINEERING MATERIALS

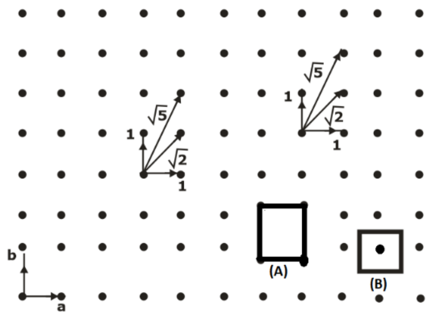
CRYSTAL STRUCTURES

- A crystalline material is one in which atoms are arranged in a regular pattern over large atomic distances.
- **Space lattice:** Infinite array of points in 3-D space in which each point located with respect to other.
- **Unit Cell** are the smallest unit of a structure which when repeated in all 3-demensions produces the crystal structure.

$$\boxed{\text{Space lattice} + \text{Basis} = \text{Unit cell}}$$

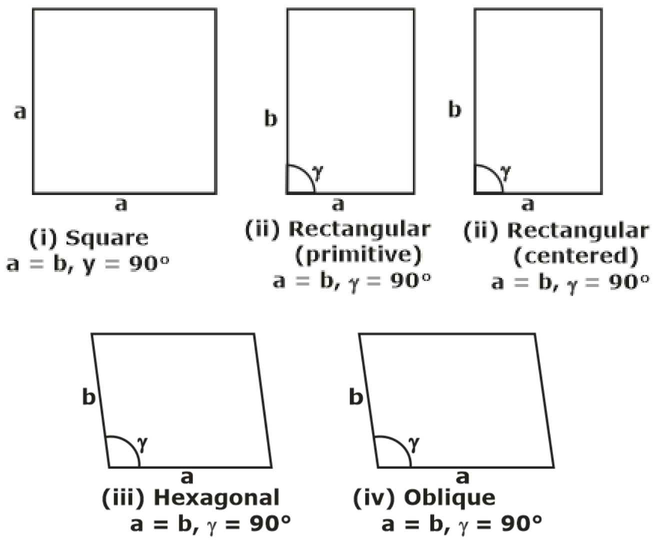
- **Primitive cell:**

  This may be defined as a geometrical shape which, when repeated indefinitely in 3-dimensions, will fill all space and is equivalent of one lattice point i.e. the unit cell that contains one lattice point only at the corners.



Crystal families and crystal class:

If all the atoms at the lattice points are identical, the lattice is said to be Bravais lattice. There are four systems and five possible Bravais lattices in two dimensions as shown in Fig. The four crystal systems of two-dimensional space are oblique, rectangular, square and hexagonal.



Bravais Lattices in two dimensions

Seven crystal systems:

Crystal family	Crystal system	Axial relationships
Isometric	Cubic	$a = b = c$ and $\alpha = \beta = \gamma = 90°$
Tetragonal	Tetragonal	$a = b \neq c$ and $\alpha = \beta = \gamma = 90°$
Orthorhombic	Orthorhombic	$a \neq b \neq c$ and $\alpha = \beta = \gamma = 90°$
Monoclinic	Monoclinic	$a \neq b \neq c$ and $\alpha = \gamma = 90°$; $\beta = 90°$
Anorthic	Triclinic	$a \neq b \neq c$ and $\alpha \neq 90°$; $\beta \neq 90°$; $\gamma \neq 90°$
Hexagonal	Hexagonal	$a = b \neq c$ and $\alpha = \beta \neq 90°$; $\gamma = 90°$;
	Trigonal	$A = b = c$, $\alpha = \beta = \gamma$; or
	Rhombohedral	$a' = b' \neq c'$ and $\alpha' = \beta' = 90°$, $\gamma' = 120°$ (Hexagonal axes)

Effective number of lattice points in the unit cell of the three cubic space lattices:

Space lattice	Abbreviation	Effective number of lattice points in unit cell
Simple cubic	SC	1
Body centred cubic	BCC	2
Face centred cubic	FCC	4

The Bravais lattices in three dimensions (the seven basic crystal systems)

Crystal system	Lattice type	No. of lattices	Examples
Cubic	P, F, C	3	Au, NaCl, CaF_2, C_rCl, CaO (I)
Monoclinic	P, B	2	$2H_2O$, $NaSO_4$, $CaSO_4$, $FeSO_4$
Triclinic	P	1	$K_2Cr_2O_7$, $CuSO_4$, $K_2S_2O_8$
Tetragonal	P, C	2	$NiSO_4$, Sn, TiO_3, and SnO_2
Orthogonal	P, B, F, C	4	$MgSO_4$, KNO_3, and $BaSO_4$
Rhombohedral (Trigonal or orthorhombic)	P or R	1	SiO_2, $CaSO_4$, and $CaCO_3$
Hexagonal	P	1	$AgCl_2$, Sio_2, Zn and Graphite

Representation of symbols:

P → primitive, B → base centred

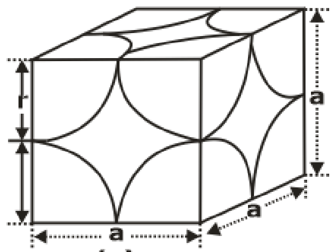
C → body centred and

F → face centred

Atomic Packing Factor (APF): This is defined as the ratio of total volume of atoms in a unit cell to the total volume of the unit cell. This is also called relative density of packing (RDP). Thus:

$$\text{APF} = \frac{\text{No. of atoms} \times \text{Volume of one atom}}{\text{Volume of unit cell}} = \frac{v}{V}$$

Simple Cubic Crystal System: (a = b = c, α = β = γ = 90):



(a)

No. of atoms in all corners: $n = \frac{1}{8} \times 8 = 1$

From the diagram: a = 2r

volume of cubic cell = $a^3 = (2r)^3$

$$\therefore \boxed{APF = \frac{1 \times \frac{4}{3}\pi r^3}{(2r)^3} = \frac{\pi}{6}(= 0.52) = 52\%}$$

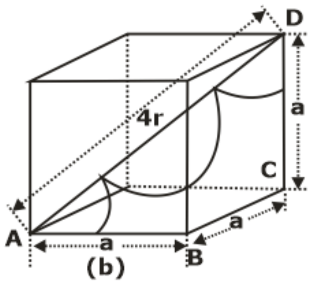
Coordination number of BCC crystal structure is 6.

Body-centred Cubic Structure (BCC):

$\therefore$ Total no. of atoms for corners $= \frac{1}{8} \times 8 = 1$ atom

BCC crystal has one atom at the centre = 1 atom

$\therefore$ Total atoms in BCC unit cell = 1 + 1 = 2 atoms



(b)

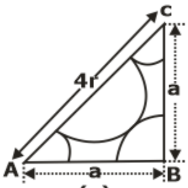
$$\boxed{a = \sqrt{\frac{16r^2}{3}} = \frac{4r}{\sqrt{3}}}$$

$$\boxed{APF = \frac{2 \times \frac{4}{3}\pi r^3}{\left(4r / \sqrt{3}\right)^3} = \frac{\sqrt{3}}{8}\pi = 0.68}$$

Coordination number of BCC crystal structure is 8.

Examples: α-Fe (below 910°C), Mo, V, Mn, Nb, W, α -Cr, δ -iron (1400°C to 1539°C), etc.

Face-centred Cubic Structure (FCC):



(c)

No. of atoms in all six faces = $\frac{1}{2}\times 6 = 3$

No. of atoms in all corners = $\frac{1}{8}\times 8 = 1$

∴ Total atoms in FCC unit cell = 1 + 3 = 4 atoms

$$\boxed{a = \sqrt{8}r = 2\sqrt{2}r}$$

$$\boxed{\therefore \text{APF} = \frac{4\times\frac{4}{3}\pi r^3}{\left(2\sqrt{2}r\right)^3} = \frac{\pi}{3\sqrt{2}} = 0.74}$$

Coordination number of BCC crystal structure is 12.

Examples: Cu, Al, Ag, Au, α-Fe, Ca, β-Co, γ-Iron (910°C to 1400°C).

Hexagonal closed packing (HCP) Structure:

The coordination number of HCP crystal is 12.

$$\boxed{\text{APF} = \frac{\pi\sqrt{2}}{6} = 0.74}$$

Examples of HCP structure are Be, Mg, Zn, Cd, Ti, Co, Hf, Se, Te, etc.

CYRSTAL DENSITY:

$$\boxed{Density = \frac{nM}{VNo}}$$

n = no. of atoms per unit cell.

M = At weight

V = Volume of unit cell

N_o = Avogadro's number (6.023×10^{23} atoms/mol).

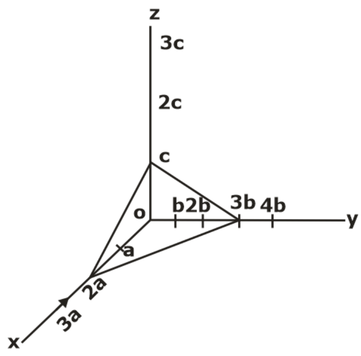
Linear Densities:

$$\boxed{\text{Linear desnity}\left(\text{LD}\right) = \frac{\text{No. of atoms centered on unit length of direction vector}}{\text{Length of the direction vector}}}$$

Planer Densities:

$$\boxed{\text{PD} = \frac{\text{No. of atoms centered on a plane}}{\text{Area of the plane}}}$$

Miller Indices: Miller indices are used to specify directions and planes.



Procedure:

(a). Identify the plane intercepts on the x, y and z-axes.

(b). Specify intercepts in fractional coordinates.

(c). Take the reciprocals of the fractional intercepts.

Notation summary:

(a). (h, k, l) represents a point – note the exclusive use of commas.

(b). Negative numbers/directions are denoted with a bar on top of the number.

(c). [h k l] represents a direction.

(d). <h k l> represents a family of directions.

(e). (h k l) represents a plane.

(f). {h k l} represents a family of planes.

Interplanar spacings:

$$\boxed{d_{hkl} = \frac{1}{\sqrt{\frac{h^2}{a^2} + \frac{k^2}{b^2} + \frac{l^2}{c^2}}}}$$

d_{hkl} gives the distance between two successive (h k l) places.

For a cubic system: a = b = c

$$\therefore \boxed{d_{hkl} = \frac{a}{\sqrt{h^2 + k^2 + l^2}}}$$

Angle between two planes or directions:

$$\boxed{\cos\theta = \frac{h_1h_2 + k_1k_2 + l_1l_2}{\sqrt{h_1^2 + k_1^2 + l_1^2} \times \sqrt{h_2^2 + k_2^2 + l_2^2}}}$$

The angle θ between the two directions or planes having Miller indices (h_1, k_1, l_1) and (h_2, k_2, l_2) respectively.

Defects and imperfections: Crystalline defects can be classified on the basis of their geometry as follows:

(i). Point imperfections

(ii). Line imperfections

(iii). Surface and grain boundary imperfections

(iv). Volume imperfections

Point Defects:

Vacancies: The simplest point defect is a vacancy i.e. an empty site of a crystal lattice which arise either from imperfect packing during original crystallization or from thermal vibrations of the atoms at higher temperature.

Interstitial Imperfections: In a closed packed structure of atoms in a crystal if the atomic packing factor is low, an extra atom may be lodged within the crystal structure.

Frenkel defect: Frenkel defect is a combination of vacancy and interstitial defects. It is ***more common in ionic crystals,*** because the positive ions, being smaller in size, get lodged easily in the interstitial positions.

Schottky defect: It is caused, whenever a pair of positive and negative ions is missing from a crystal. ***It maintains a charge neutrality.***

Linear Detects:

a. Edge Dislocation: An extra half plane of atoms is introduced into the crystal structure. The dislocation line is perpendicular to burger vector.

The elastic strain energy E per unit length of a dislocation of Burgers vector b can be expressed approximately by

$$E = \frac{\mu b^2}{2}$$

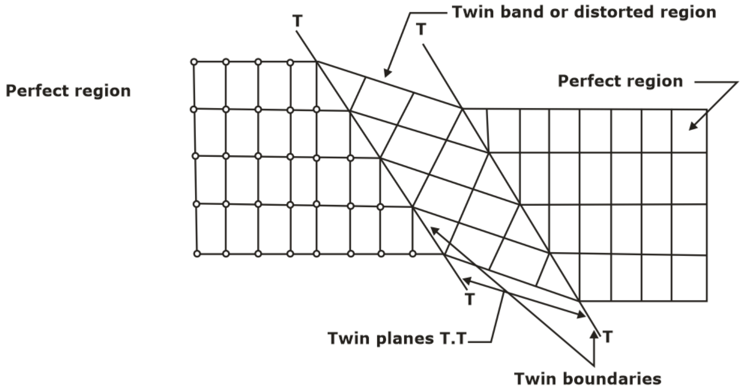
b. Screw Dislocation: Dislocation is formed by shear stress; the upper front region of the crystal is shifted one atomic distance to the right relative to the bottom portion.

The dislocation line is parallel to burger vector.

Surface and grain boundaries:

a. High angle and low angle grain boundaries: When the orientation difference between neighbouring grains is more than 10°-15°, boundaries are called high angle grain boundaries. While in case of low angle grain boundaries this orientation mismatch is not more than of 5°.

b. Twin boundaries: Here, the atomic arrangement on one side of a twin boundary is a mirror reflection of the arrangement on the other side.



Strengthening Mechanisms and phase diagrams:

Strengthening Mechanisms:

Any restriction to the movement of the dislocations are said to increase the strength of the material.

Strengthening Mechanisms

In single phase materials
1. Grain size reduction
2. Solid Solution Strengthening
3. Strain Hardening

In multi phase materials
1. Precipitation Hardening
2. Dispersion Hardening
3. Fibre strengthening
4. Martensite strengthening

Solid solution strengthening:

Hume-Rothary rule: It gives Conditions for unlimited solubility.

1. Difference in atomic radius of both the materials should be less than 15 %.
2. Crystal Structure: The materials must have the same crystal structure.
3. Valency of both the materials should be same.
4. Electronegativity and electron affinity of both the materials should be comparative. Alloying the element either produces interstitial or substitutional impurity.

Grain size strengthening: Yield strength is related to grain size (diameter, d) as Hall Petch relation:

$$\boxed{\sigma_y = \sigma_o + Kd^{-1/2}}$$

Strain hardening:

Dislocation density (ρ) and shear stress (τ) are related as follows:

$$\boxed{\tau = \tau_o + A\sqrt{\rho}}$$

Percentage cold work is given by:

$$\boxed{\%CW = \frac{A_o - A_d}{A_o} \times 100\%}$$

Where:

A_o = Original Area of specimen

A_d = area after deformation

PHASE:

A phase is a physically distinct, chemically homogeneous, and mechanically separable region in a system in equilibrium.

According to Gibb's Phase Rule:

$$\boxed{F + P = C + 2}$$

where, F = No. of degrees of freedom.

P = No of phases present.

C = No. a component

2 is for temperature and pressure.

When pressure is held constant

F+ P = C+1, 1 is only for temperature.

Type of Phase Diagram

Unary phase diagram (single component): Example: Water, graphite, metallic carbon, diamond.

Binary phase diagram (two components):

Type 1 (Binary Isomorphous Systems): The materials which are completely soluble in liquid as well as solid state.

Type-II: Two Components are Completely Soluble in Liquid State and are Completely insoluble in each Other in Solid State.

Example: Bismuth-cadmium system

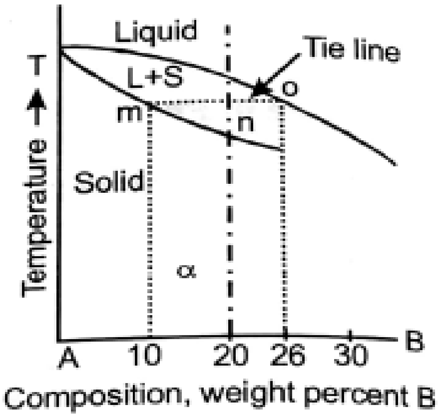
Type III: Two Components are Completely Soluble in Liquid State and are Partially Soluble in Solid State.

Examples: Pb-Sn, Cu-Ag, Pb-Sb, Cd-Zn, Sn-Bi, etc.

Type IV: When two metals are completely soluble in liquid state, show partial solubility in the solid state, and it their melting points are vastly different from each other, then, a peritectic phase diagram may result.

LEVER RULE:

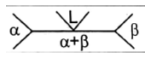
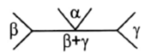
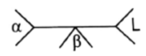
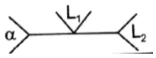
Draw a horizontal line until it intersects the curve on both sides. This line is called tie line.



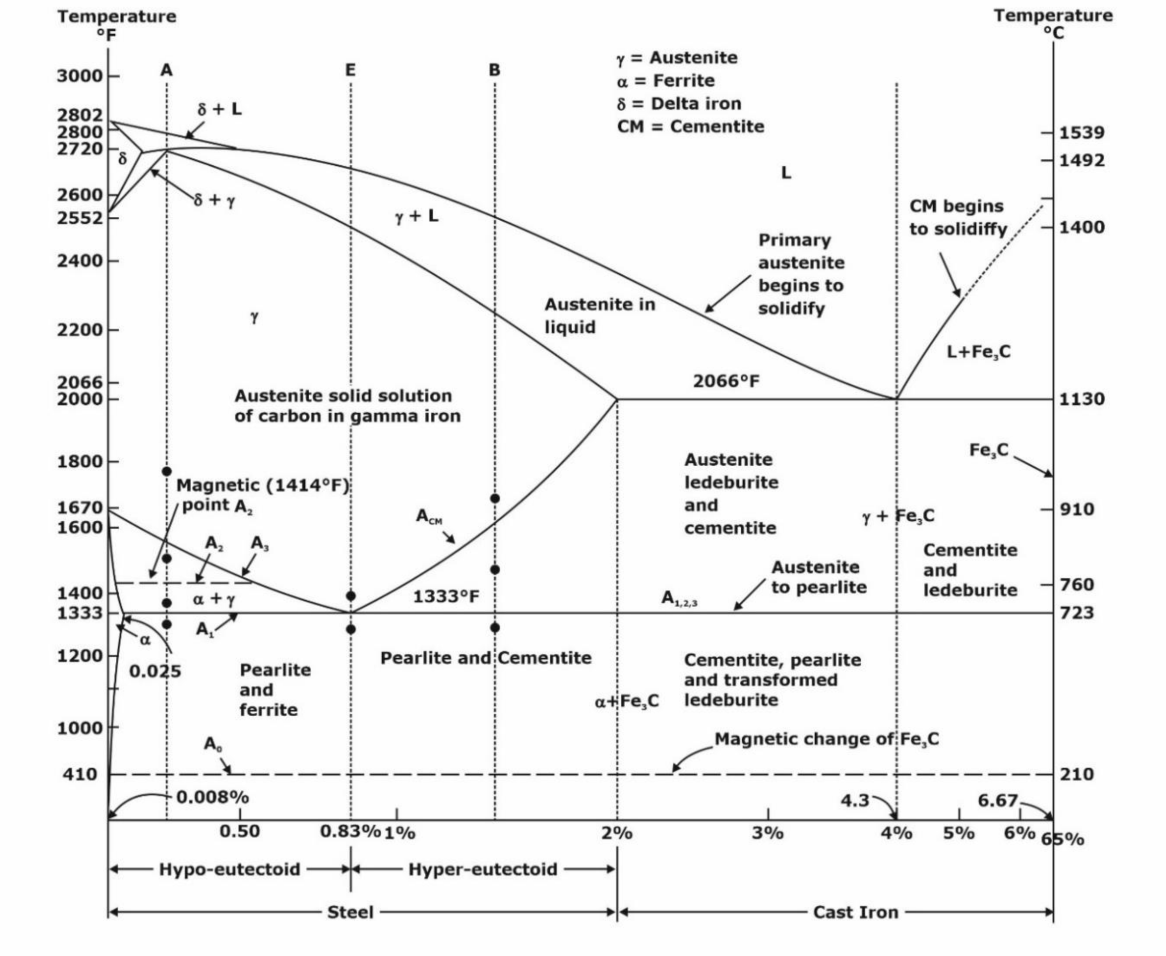
$$\boxed{\text{Liquid}(\%) = \frac{mn}{mo} \times 100}$$

$$\boxed{\text{Solid}(\%) = \frac{no}{mo} \times 100}$$

Various types of phase Diagram Reaction

Reaction	Symbolic equation	Schematic presentation	Example
Eutectic	$L \leftrightarrow \alpha + \beta$		Fe-C, 4.27C%, 1147°C
Eutectoid	$\alpha \leftrightarrow \beta + \gamma$		Fe-C, 0.80C%, 723°C
Peritectic	$L + \alpha \leftrightarrow \beta$		Fe-C, 0.16C%, 1495°C
Peritectoid	$\alpha + \beta \leftrightarrow \gamma$		
Monotectic	$L_1 \leftrightarrow L_2 + \alpha$		Fe-C, 0.51C%, 1495°C

Iron-carbon phase diagram:



α-ferrite: It is a solid solution of ***BCC iron*** and carbon with maximum solubility of carbon is 0.022% at 727°C. It is softest phase and act as matrix of a composite material.

γ-iron or austenite: It is a solid solution of FCC iron and carbon with maximum solubility of 2.11% C at 1148°C.It is present between temperature limits from (910°C to 1395°C).

Cementite or Fe_3C: It is 100% iron carbide having maximum solid solubility of 6.67% C. It is ***very hard and brittle intermetallic compound*** and has significant influence on the properties of steel.

Peritectic reaction at 1495°C and 0.16%C.

δ-ferrite + L ↔ γ-iron (austenite)

Monotectic reaction 1495°C and 0.51%C.

L ↔ L+ γ-iron (austenite)

Eutectic reaction: at 1147°C and 4.3%C.

L ↔ γ-iron + Fe_3C (cementite) [ledeburite].

Eutectoid reaction: at 723°C and 0.8%C.

γ-iron L ↔ α-ferrite + Fe_3C (cementite) [pearlite]

Types of steels:

Low Carbon steels: C < 0.25 wt%. These are unresponsive to heat treatments intended to form martensite; strengthening is accomplished by cold work.

Medium carbon steels: 0.25 wt% < C < 0.60 wt%. These alloys may be heat treated by austenitizing, quenching, and then tempering to improve their mechanical properties.

High-carbon steels: 0.60 wt% < C < 1.4 wt%, are the hardest, strongest, and yet least ductile of the carbon steels.

Cast Irons: Generically, cast irons are a class of ferrous alloys with carbon contents above 2.14 wt%; in practice, however, most cast irons contain between 3.0 and 4.5 wt% C and with other alloying elements.

Gray Cast Iron: C varies from 2.5 to 4.0 wt% and Si varies from 1.0 to 3.0 wt%, respectively. The graphite exists in the form of flakes (similar to corn flakes).

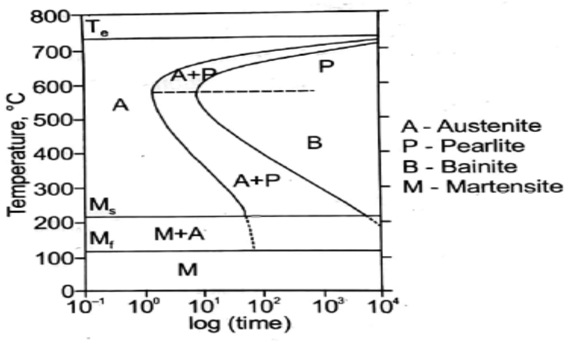
Ductile (or Nodular Iron): It is obtained by adding a small amount of magnesium and/or cerium to the gray iron. Graphite still forms, but as nodules or sphere-like particles.

White Cast Iron: Most of the carbon exists as cementite instead of graphite. Due to large amounts of the cementite phase, white iron is extremely hard and brittle (unmachinable).

Malleable cast iron: Heating white iron at temperatures between 800°C and 900°C for a prolonged time period and in a neutral atmosphere (to prevent oxidation) causes a decomposition of the cementite, forming graphite, which exists in the form of clusters or rosettes surrounded by a ferrite or pearlite matrix.

TTT DIAGRAMS: While quenching austenite below 725° C, it was observed that for some time there was no change in the microstructure this period is called incubation time.

- Incubation time decreases as the temperature of quenching decreases.



Quenching medias and their severity:

"Severity of quench" is a term often used to indicate the rate of cooling, the more rapid the quench, the more severe the quench. Quenching media with severity:

Brine > water > oil > air

Brine produces the most severe quench, followed by water and then oil, which is more effective than air.

Martensite:

Martensite is a ***body-centered tetragonal (BCT)*** form of iron in which some carbon is dissolved. The transformation to martensite does not involve atom diffusion, but rather occurs by a sudden diffusion-less shear process.

Bainite:

Bainite is formed at cooling rates slower than that for martensite formation and faster than that for ferrite and pearlite formation. Upper bainite generally forms at temperatures between 550 and 400°C and Lower bainite generally forms at temperatures between 400 and 250°C.

HEAT TREATMENT:

a. Annealing:

Process Annealing: used to negate the effects of cold work—that is, to soften and increase the ductility of a previously strain-hardened metal.

Stress Relief annealing: It is used to relieve internal residual stresses developed due to nonuniform distortion and warpage.

Full Annealing:

For hypoeutectoid steels: at about 50°C above the A_3 line (to form austenite).

For hypereutectoid steels: 50° C above the A_1 line.

The microstructural product of this anneal is coarse pearlite that is relatively soft and ductile.

Spheroidizing: A coalescence of the Fe_3C to form the spheroid particles.

b. NORMALIZING:

For hypoeutectoid steels: at about 55°C above the A_3 line (Upper critical temperature).

For hypereutectoid steels: 55° C above the A_{cm} line.

The sample is cooled in air. It is used to refine the grains (i.e., to decrease the average grain size) and produce a more uniform and desirable size distribution.

c. TEMPERING: used to relive residual stress, improve ductility and Toughness.

Surface Hardening Mechanisms:

CASE HARDENING:

(i). In Pack Carburizing Piece is surrounded by a carburizing mixture and packed in a steel box.

Carburizing mixture: 50% charcoal + 20% $BaCO_3$ + 5% $CaCO_3$ + 5-12% Na_2CO_3

(ii). In Gas Carburizing work-part is treated in an atmosphere of gases containing carbon and hydrocarbon gases such as CH4, butane etc.

(iii). In Liquid Carburizing Workpiece is heated to 950°C and dipped in a molten salt bath containing 20% NaCN, which provides Carbon & Nitrogen.

Nitriding is done by heating steel in the atmosphere of NH_3 gas. It produces the hardest surface of steel.

Cyaniding: work part is immersed in molten salt bath containing sodium cyanide (NaCN) which is heated to 820-860°C.Mixture is 20-30% NaCN + 25-50% NaCl + 25-50% Na_2CO_3

Flame Hardening Process consists of heating the surface of high carbon steels by a high temperature gas flame at 2400-3500°C, followed by immediate cooling is air or water.

Induction hardening: Workpieces is heated in an induction furnace surrounded by copper coils which are water cooled. High frequency AC current is passed through Cu coils and thus alternate magnetic field set up which induce eddy currents on the surfaces.

Effects of alloying elements:

Element	Effect(s)
Mn	Increase hardenability Increase resistance Reduces ductility and weldability Increase hardenability significantly
Mo	Increase strength, toughness, red hardness, and hot When used with Cr, Mn, and V Enhances corrosion and abrasion resistance
Ni	Increases toughness and impact resistance
P	Increases strength in low carbon steel Improves corrosion resistance
Si	Strengthens low alloy steels Increases hardenability Acts as deoxidizer Improves magnetic properties when present in large percentage.
S	Improves machinability of very low carbon steels
Ti	Increases austenitic hardenability Reduces martensitic hardness in Cr steels
V	Increases strength while retaining ductility Produces fine grain size Increases hardenability
W	Imparts hardness and wear resistance Significantly improves red hardness Imparts strength temperature

CHAPTER 3: FORMING

Introduction: Metal Forming is the manufacturing process in which the parts are produced by plastic deformation.

Types of metal forming:

Cold working: plastic deformation of metals and alloys at a temperature below their recrystallization temperature. Parts produced from it have better dimensional accuracy, better surface finish, residual stresses, large power requirement.

$T < 0.3\ T_m$

Warm Forming: Metal deformation carried out at temperatures intermediate to hot and cold forming.

$0.3\ T_m < T < 0.5\ T_m$

Hot working: Plastic deformation of metals and alloys at such a temperature above recrystallization temperature at which recovery and recrystallization take place simultaneously with the strain hardening.

$T > 0.6\ T_m$

Parts produced from hot working have poor surface finish, poor dimensional accuracy, less power requirement.

Typical values for different type metalworking:

Category	Temperature range	Strain rate sensitivity exponent	Coefficient of friction
Cold working	$\leq 0.3T_m$	$0 \leq m \leq 0.05$	0.1
Warm working	$0.3T_m - 0.5\ T_m$	$0.05 \leq m \leq 0.1$	0.2
Hot working	$0.5T_m - 0.75\ T_m$	$0.05 \leq m \leq 0.4$	0.4 – 0.5

Classification of metalworking processes:

1. Direct compression type: Forging and Rolling

2. Indirect compression type: Wire drawing, Extrusion, Deep drawing

3. Tension type: Stretch Forming

4. Bending type: Bending of sheets

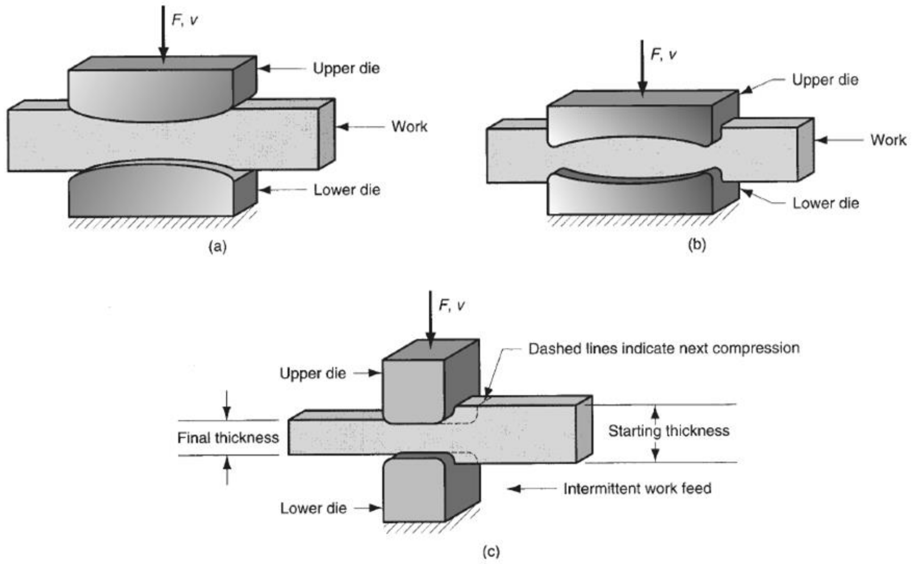
5. Shearing processes: Blanking, Coining, Joggling, Twisting.

Forging: Forging is a basic process in which the work piece is shaped by compressive forces applied through various dies and tooling.

Open die forging: In this, the work piece is compressed between two platens. There is no constraint to material flow in lateral direction.

- In edging the cross-section area is increased.
- In fullering cross section area is decreased and length is increased.

- In Upsetting forging major length of part is in die and some part is out of die. Force is applied parallel to axis to increase area of part outside the die. It is used to produce bolt heads.



Open die forging operations: (a) fullering, (b) edging, and (c) cogging

Impression die forging: In impression die forging, the work piece is pressed between the dies. As the metal spreads to fill up the cavities sunk in the dies, the requisite shape is formed between the closing dies.

Some material which is forced out of the dies is called "flash".

Closed die forging: It is very similar to impression die forging, but in true closed die forging, the amount of material initially taken is very carefully controlled, so that no flash is formed**.**

Drop forging: It utilizes a closed impression die to obtain the desired shape of the component. The shaping is done by the repeated hammering given to the material in the die cavity. The equipment used for delivering the blows are called drop hammers.

Press forging: In press forging the metal is shaped not by means of a series of blows as in drop forging, but by means of a single continuous squeezing action.

Swaging: Swaging is a special variation of impact forging where the repeated blows are obtained by a radial movement of shaped dies.

Analysis of forging:

Volume before forging = Volume after forging

$$\frac{\pi}{4} d_0^2 \times h_0 = \frac{\pi}{4} \times d_1^2 \times h_1$$

$$\boxed{d_1 = d_0 \sqrt{\frac{h_0}{h_1}}}$$

Forging force calculation is done based on final dimensions.

$$\boxed{F_{act} = \sigma_y \times A_f \left[1 + \frac{2\mu r_f}{3h_f}\right]}$$

Where A_f = final cross section area, r_f = final radius, h_f = final height.

True stress:

$$\boxed{(\sigma_T) = \frac{\text{load}}{\text{Instantaneous area}} = \sigma(1+\varepsilon)}$$

Where σ = engineering stress

ϵ = engineering strain

True strain is given by:

$$\boxed{(\varepsilon_T) = \int_{L_o}^{L} \frac{dx}{x} = \ln\left[\frac{L}{L_o}\right] = \ln(1+\varepsilon) = \ln\left[\frac{A_o}{A}\right] = 2\ln\left[\frac{d_o}{d}\right]}$$

Flow stress is given by the power law:

$$\boxed{\sigma_T = K(\epsilon_T)^n}$$

Thus, mean flow stress is given by:

$$\boxed{\sigma_0 = \frac{K\varepsilon_T^n}{n+1}}$$

Forging defects:

(i). Barrelling is the defect when material near plates does not flow and material in middle flow.

(ii). Die shift

(iii). Cold shut

Rolling: In this process, metals and alloys are plastically deformed into semi-finished or finished products by being pressed between two rolls which are rotating.

$V_{\text{top roller}} = V_{\text{bottom roller}}$

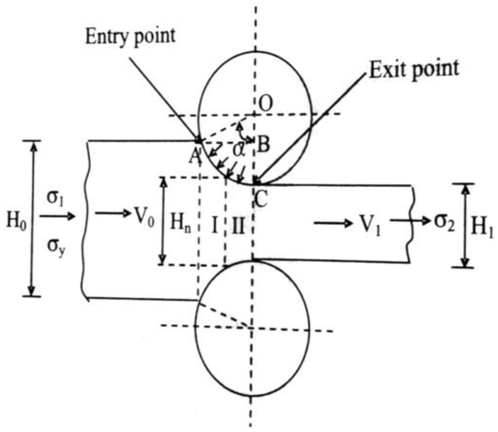
$$\left(\frac{\pi DN}{60}\right)_{top} = \left(\frac{\pi DN}{60}\right)_{bottom}$$

$D_t N_t = D_b N_b$

$H_0 B_0 V_0 = H_1 B_1 V_1$

$$\frac{H_0}{H_1} = \frac{V_1}{V_0} (\because H_0 > H_1)$$

$\Rightarrow V_1 > V_0$



ΔH = reduction in thickness = $(H_0 - H_1)$

α = Deformation angle (or) Bite angle (or) Angle of bite.

$$\boxed{\Delta H = D(1 - \cos\alpha)}$$

Length of Contact : $\boxed{L = \sqrt{R\Delta H}}$

Maximum reduction possible per pass: $\boxed{\Delta H_{max} = \mu^2 R}$

The neutral point defined in the deformation zone is dividing the deformation zone into two zones:

(i). The zone between the entry and neutral points is called "lagging zone".

(ii). The zone between neutral point and exit is called "leading zone".

At the entry, the velocity of the strip is much less than the velocity of the roller, the relative velocity between rollers and the strip is maximum.

(a). When we are moving along the deformation zone because of increase of velocity of strip their relative velocity is reducing.

(b). At the neutral point the relative velocity becomes equal to zero.

(c). Beyond the neutral point the relative velocity again increasing in the opposite direction and becomes maximum at the exit. But the maximum relative velocities at the entry and at exit are not equal.

From the above in the deformation zone the relative velocity is reducing first and then increasing, whereas in lagging zone relative velocity is reducing and in leading zone relative velocity is increasing.

As slip ∝ Relative velocity

$$\boxed{\text{Backward slip} = \frac{V - V_0}{V} = 1 - \frac{V_0}{V}}$$

The maximum % slip taking place in the leading zone is called as "forward slip".

$$\boxed{\text{Forward slip} = \frac{V_1 - V}{V} = \frac{V_1}{V} - 1}$$

- In the deformation zone the pressure is increasing first and then decreasing:

$$n = \frac{2\mu L}{\Delta H}$$

μ = coefficient of friction

$$(P_x)_{lag} = \left(\frac{\sigma_y}{n}\right)\left[(n-1)\left(\frac{H_0}{H_x}\right)^n + 1\right] - \left(\frac{H_0}{H_x}\right)^n \sigma_1$$

$$(P_x)_{lead} = \left(\frac{\sigma_y}{n}\right)\left[(n+1)\left(\frac{H_0}{H_x}\right)^n - 1\right] - \left(\frac{H_0}{H_x}\right)^n \sigma_1$$

H_x = Thickness of stirp in leading zone at a distance of 'x'.

$P_{x,\,lag}$, $P_{x,\,lead}$ is pressure in lag and lead zones at a distance x respectively.

σ_2 = front tension (not compulsory)

At the neutral point the pressure is equal:

$(P_n)_{lagging} = (P_n)_{leading}$

Rolls Power: P = 2Tω (As two power rollers considered)

T = Torque required per single roller

Angular velocity: $\boxed{\omega = \frac{2\pi N}{60}}$

N = rpm of rollers

$T = F_{avg} \times a$

Moment arm: a = λL

$T = F_{avg} \times \lambda L$

λ (arm factor) = 0.3 to 0.5

$$\boxed{P_{avg} = \frac{2}{\sqrt{3}}\sigma_y \times \left(1 + \frac{\mu L}{4H}\right)}$$

Where $H = \frac{H_0 + H_1}{2}$

Defects in Rolling:

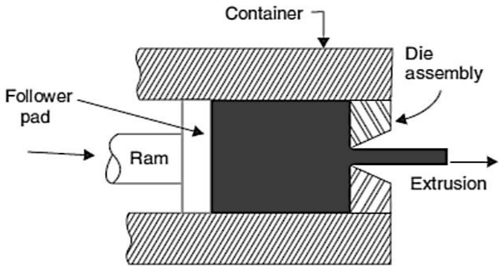
- Alligatoring
- Wavy edges

Extrusion: Extrusion is a process in which the metal is subjected to plastic flow by enclosing the metal in a closed chamber in which the only opening provided is through a die.

Types of Extrusion Processes:

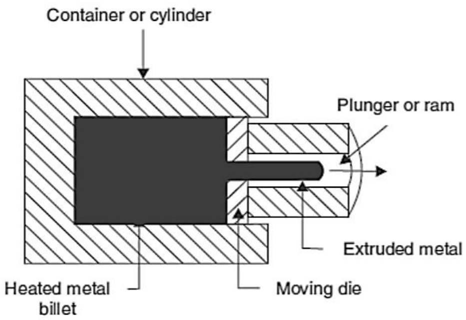
These are mainly Forward extrusion or backward extrusion. These two can be in both the hot and cold conditions:

Forward or Direct extrusion: A metal billet is loaded into a container, and a ram compresses the material, forcing it to flow through one or more openings in a die at the opposite end of the container.



Forward or direct extrusion

Backward or Indirect extrusion: The die is mounted to the ram rather than at the opposite end of the container. As the ram penetrates the work, the metal is forced to flow through the clearance in a direction opposite to the motion of the ram. Since the billet is not forced to move relative to the container, there is no friction at the container walls, and the ram force is therefore lower than in direct extrusion.



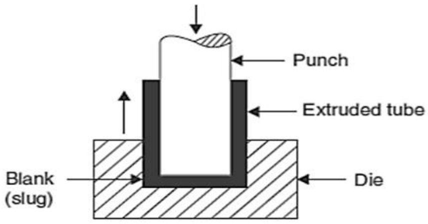
Backward or Indirect extrusion

Hot extrusion vs cold extrusion: Metals that are typically extruded hot include aluminium, copper, magnesium, zinc, tin, and their alloys. These same metals are sometimes extruded cold. Steel alloys are usually extruded hot, although the softer, more ductile grades are sometimes cold extruded (e.g., low carbon steels and stainless steel).

Cold Extrusion Processes:

(a). Hydrostatic extrusion: This is a direct extrusion process. But the pressure is applied to the metal blank on all sides through a fluid medium.

(b). Impact extrusion: Collapsible bottles are made by impact extrusion.



Impact extrusion

Calculations in Extrusion:

Extrusion or reduction ratio: $\boxed{R = \frac{A_0}{A_f}}$

Where A_o and A_f are the original and final areas, respectively.

Johnson's equation:

$$\boxed{\sigma = \sigma_o[a + b\ln R]}$$

Where a and b are Johnson's constants, σ_o is the nominal stress and R is the extrusion ratio.

$$\boxed{\sigma_0 = \frac{K\varepsilon_T^n}{n+1}}$$

Slab Method: $\boxed{\sigma_E = \sigma_y\left(\frac{1+B}{B}\right)\left[1-\left(\frac{A_f}{A_0}\right)^B\right]}$

Where B = μ.cot α

μ = coefficient of friction

α = semi die angle

For Plane strain: $\boxed{\sigma_y = \frac{2\sigma_o}{\sqrt{3}}}$

For Plane stress: $\boxed{\sigma_y = \sigma_o}$

For Hot Extrusion:

$$\boxed{\sigma_d = k_1 \ln R}$$

K_1 = Extrusion constant which depends upon the temperature

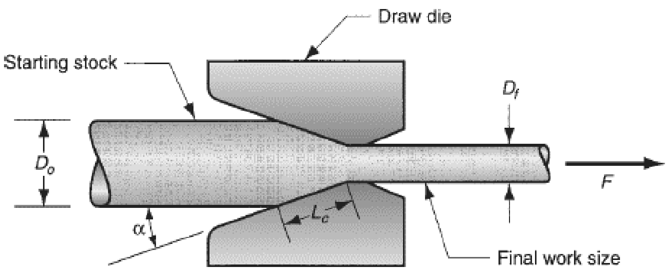
Extrusion defects:

Surface Cracking: Sometimes the surface of extruded metal/products develops surface cracks. If extrusion temperature, friction, or speed is too high, surface temperatures can rise significantly, which may cause surface cracking and tearing.

Piping: The type of metal-flow pattern in extrusion tends to draw surface oxides and impurities toward the centre of the billet-much like a funnel. This defect is known as pipe defect, tailpipe, or fishtailing.

Wire drawing: Wire drawing process is a cold working process used to produce wires from solid rods by pulling through a stationary die.

Analysis of wire drawing operation



Original area: $A_0 = \frac{\pi}{4}D_0^2$

Final Area: $A_f = \frac{\pi}{4}D_f^2$

The draft is simply the difference between original and final stock diameters:

$\boxed{d = D_o - D_f}$

In a drawing operation, the change in size of the work is usually given by the area reduction, defi ned as follows:

% Reduction in area: $\boxed{r = \frac{A_0 - A_f}{A_0}}$

Contact length (L_c) of the work with the draw die: $\boxed{L_c = \frac{D_0 - D_f}{2\sin\alpha}}$

Mechanics of drawing: $\boxed{\varepsilon = \ln\frac{A_o}{A_f} = \ln\frac{1}{1-r}}$

Drawing stress (σ_d) is given by:

$$\boxed{\sigma_d = \sigma_y\left(\frac{1+B}{B}\right)\left[1-\left(\frac{A_f}{A_0}\right)^B\right] + \sigma_b\left(\frac{A_f}{A_0}\right)^B}$$

Where σ_b = Back pull stress

B = μcot α

μ = coefficient of friction

α = semi die angle

Drawing Force: $F = \sigma_d \times A_f$

When $\sigma_b = 0$, Back pull stress

$$\boxed{\sigma_d = \sigma_y\left(\frac{1+B}{B}\right)\left[1-\left(\frac{A_f}{A_0}\right)^B\right]}$$

For maximum reduction case: $\boldsymbol{\sigma_d = \sigma_y}$

$$\Rightarrow \frac{\sigma_d}{\sigma_y} = 1$$

$$\text{But, } \frac{\sigma_d}{\sigma_y} = \left(\frac{1+B}{B}\right)\left[1-\left(\frac{A_f}{A_0}\right)^B\right]$$

$$\therefore \left(\frac{1+B}{B}\right)\left[1-\left(\frac{A_1}{A_0}\right)^B\right] = 1$$

Under ideal conditions of wire drawing operation, the coefficient of friction is assumed to be zero.

Therefore, $\mu = 0 \Rightarrow B = 0$

$$\boxed{\sigma_{d\,(\text{ideal})} = \sigma_y \ln \frac{A_0}{A_f}}$$

Sheet metal working operations: The basic cutting operations which come under Sheet Metal Operations are:

(a). Punching Operation

(b). Blanking Operation

(a). Punching Operation: When the force is applied by using the punch on to the sheet, the cutting or shearing action will be taking place in the sheet producing piece/blank leaving a hole in the sheet.

In punch and die working, if the sheet with the hole is useful, it is called Punching or Piercing operation.

$$\boxed{\begin{array}{l}\text{Punch Size} < \text{Die Size (Basic Requirement)} \\ \text{Punch Size} = \text{Hole Size (Needed)}\end{array}}$$

Clearance $\rightarrow$ Die.

Shear $\rightarrow$ Punch.

(b). Blanking Operation: In punch and die working, if the Piece/blank produced in the sheet is useful, it is called as Blanking operation.

In blanking Operation, the die size is made equal to blank size and clearance is provided only on the Punch.

$$\boxed{\begin{array}{l}\text{Blank Size} = \text{Die Size (Basic Requirement)} \\ \text{Punch Size} = \text{Die size} - 2C\,\text{(Needed)}\end{array}}$$

- Clearance $\rightarrow$ Punch.
- Shear $\rightarrow$ Die.

Analysis of punching and blanking

- Optimum Radial clearance: $\boxed{C = 0.0032t\sqrt{\tau_u}}$

- $\boxed{F_{max} = A_s \times \tau_u}$

A_s = shearing area = p × t

Where p is the perimeter of the hole.

τ_u = ultimate shear stress

- For rectangular blanks with length L and width b

$$\boxed{F_{max} = 2(L + b)\ t.\tau_u}$$

- Work done = Force × distance

$$\boxed{\text{Work Done} = F_{max} \times Kt}$$

K = % penetration required for completing the shearing action.

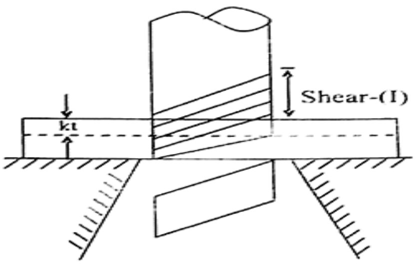
$$\boxed{d_{min}(\text{Smallest Diameter}) = \frac{4t\tau_u}{\sigma_{c,allowable}}}$$

Methods of reducing punch force: It is done by providing shear on punch. Energy required if shear is provided

$\boxed{\text{Energy required} = F \times (Kt + I)}$ (always $F < F_{max}$).

The energy required for punching or blanking is remains same with and without provided shear:

$$\boxed{\begin{aligned} &F_{max}.\ K.t = F\ (K.t + I) \\ &F = \left[\frac{F_{max}Kt}{(Kt + 1)}\right] \end{aligned}}$$



Slotting is the term sometimes used for a punching operation that cuts out an elongated or rectangular hole.

Perforating involves the simultaneous punching of a pattern of holes in sheet metal.

Notching involves cutting out a portion of metal from the side of the sheet or strip. Seminotching removes a portion of metal from the interior of the sheet.

Lancing: It is creating a tab on the edge without removal of material.

Nibbling: The process of creating a profile in the sheet is called nibbling.

Parting: Shearing the plates into two parts.

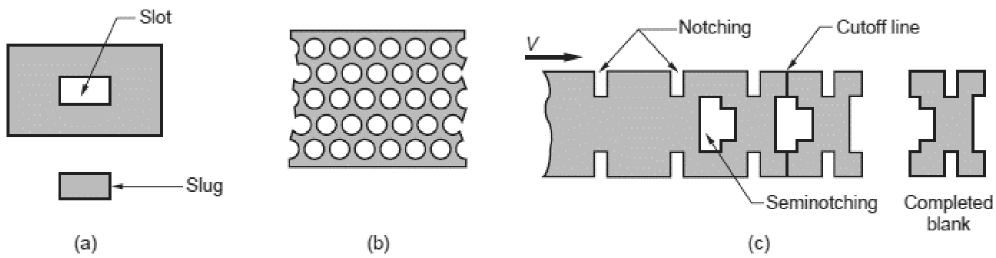
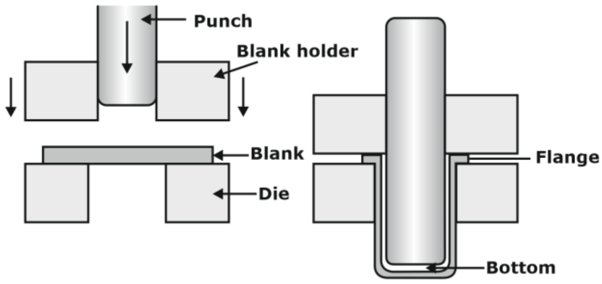


Figure: a) Slotting, (b) perforating, (c) notching and semi notching.

Deep drawing: It is a Sheet Metal forming process in which a sheet metal blank is radially drawn into a forming die by the mechanical action of a punch.

If $\frac{h}{d} \geq 0.5$ it is called deep drawing.

If $\frac{h}{d} < 0.5$ is called shallow drawing.



Blank diameter is given by:

$\boxed{D = \sqrt{d^2 + 4dh}}$ if $\frac{d}{r} \geq 20$

$\boxed{D = \sqrt{d^2 + 4dh} - \frac{r}{2}}$ If $\frac{d}{r} = 15$ to 20

$\boxed{D = \sqrt{d^2 + 4dh} - r}$ If $\frac{d}{r} = 10$ to 15

Draw ratio : $\boxed{DR = \frac{\text{Blank Diameter}}{\text{Punch Diameter}}}$

An approximate upper limit on the drawing ratio is a value of 2.0.

$$DR_1 = \frac{D}{d_1}$$

$$DR_2 = \frac{d_1}{d_2}$$

$$DR_3 = \frac{d_2}{d_3}$$

Deep Drawing force is given by: $\boxed{F = \pi D_p t(TS)\left(\frac{D_b}{D_p} - 0.7\right)}$

Where t original blank thickness, mm; TS = tensile strength, MPa and D_b and D_p are the starting blank diameter and punch diameter, respectively.

Drawing Without a Blank holder: One of the primary functions of the blank holder is to prevent wrinkling of the flange while the cup is being drawn. The tendency for wrinkling is reduced as the thickness-to-diameter ratio of the blank increases. If the t/D_b ratio is large enough, drawing can be accomplished without a blank holder. The limiting condition for drawing without a blank holder can be estimated from the following:

$$\boxed{D_b - D_p < 5t}$$

Defects in Drawing:

(a). Wrinkling in the flange: Wrinkling in a drawn part consists of a series of ridges that form radially in the undrawn flange of the work part due to compressive buckling.

(b). Wrinkling in the wall: If and when the wrinkled flange is drawn into the cup, these ridges appear in the vertical wall.

(c). Tearing: Tearing is an open crack in the vertical wall, usually near the base of the drawn cup, due to high tensile stresses that cause thinning and failure of the metal at this location. This type of failure can also occur as the metal is pulled over a sharp die corner.

(d). Earing: This is the formation of irregularities (called ears) in the upper edge of a deep drawn cup, caused by anisotropy in the sheet metal. If the material is perfectly isotropic, ears do not form.

(e). Surface scratches: Surface scratches can occur on the drawn part if the punch and die are not smooth or if lubrication is insufficient.

Bending operation:

Bend allowance: $L_b = r_n \times \phi$

r = inside radius

Neutral plane radius: $r_n = r + Kt$

Where K = Stretch factor or bend factor

Thus: $\boxed{L_b = \varphi[r + Kt]}$

Where ϕ is in radians.

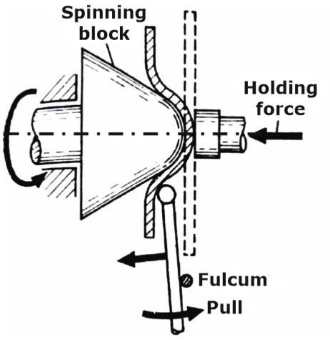
$$K = \frac{1}{3} \text{ if } r < 2t \text{ and } K = \frac{1}{2} \text{ if } r \geq 2t$$

Spring back: It is the elastic recovery partially toward its original shape. In overbending, the punch angle and radius are fabricated slightly smaller than the specified angle on the final part so that the sheet metal springs back to the desired value.

Bending force: $\boxed{F = \dfrac{K(TS)wt^2}{D}}$

where F = bending force, N; TS = tensile strength of the sheet metal, MPa; w = width of part in the direction of the bend axis, mm; t = stock thickness, mm; and D = die opening dimension.

Spinning: In the spinning process, an object with surface of revolution is produced from a sheet metal.



(a) Spinning

The thickness of the sheet after the spinning operation is given by:

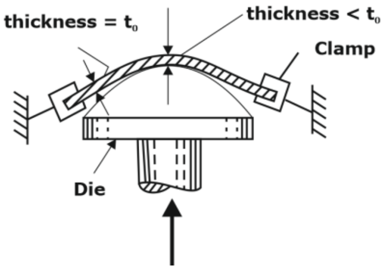
$$\boxed{t_c = t_b \sin\alpha}$$

where α is the semi die angle.

t_c=Thickness of sheet after spinning.

t_b=Thickness of sheet before spinning.

Stretch forming: a metal forming process in which a piece of sheet metal is stretched and bent simultaneously over a die in order to form large, contoured parts.



For biaxial stretching of sheets:

$$\varepsilon_1 = \ln\left(\frac{L_{i1}}{L_{o1}}\right), \varepsilon_2 = \ln\left(\frac{L_{i2}}{L_{o2}}\right)$$

Where ϵ_1 is the true strain for the one part of sheet and ϵ_2 is the true strain for the other part of the sheet.

$$\boxed{\text{Final thickness}(t_f) = \frac{\text{Initial thickness}(t_i)}{e^{\varepsilon_1} \times e^{\varepsilon_2}}}$$

Ironing Force: The objective is only to reduce the wall thickness of the cup and hence, no blank holding is required because the punch is fitted closely inside the cup.

Ironing force: $\boxed{P = \pi d_1 t_1 s_{av} \log_e \frac{t_0}{t_1}}$

Where

F = Ironing force, N

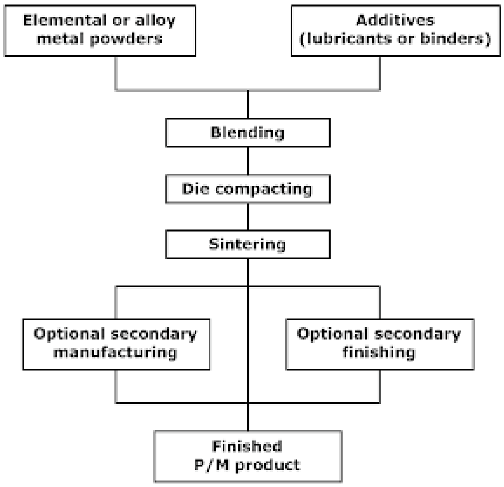
d_1 = Mean diameter of the shell after ironing,

t_1 = Thickness of shell after ironing,

t_0 = Thickness of the shell before ironing, and

S_{av} = Average of tensile strength before and after ironing.

Powder metallurgy:



Blending: Blending or mixing operations can be done either dry or wet. Lubricants such as graphite or stearic acid improve the flow characteristics and compressibility at the expense of reduced strength.

Compacting: Powder is pressed into a "green compact" and still very porous, ~70% density.

Sintering: Controlled atmosphere: no oxygen, Heat to $0.75T_m$, Particles bind together and density increase, up to 95%.

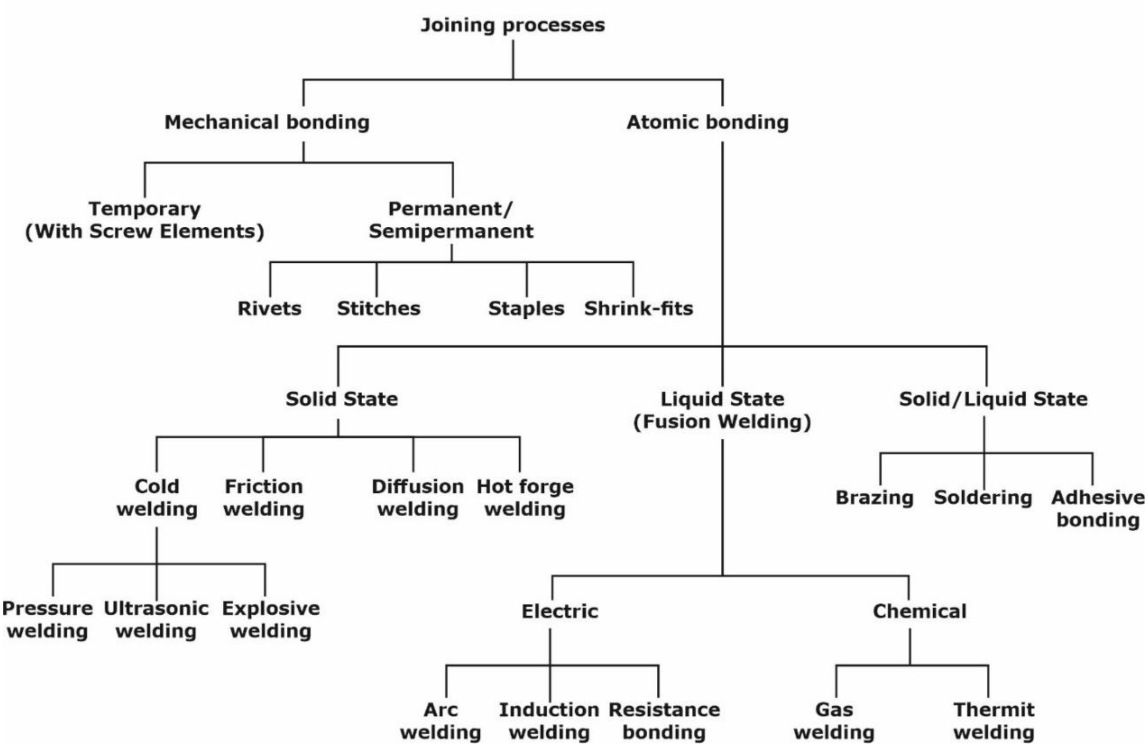
Infiltration: The liquid would flow into the voids simply by capillary action, thereby decreasing the porosity and improving the strength of the component.

Impregnation: It is used for self-lubrication under action conditions. The liquid would flow into the voids simply by capillary action.

CHAPTER 4: JOINING

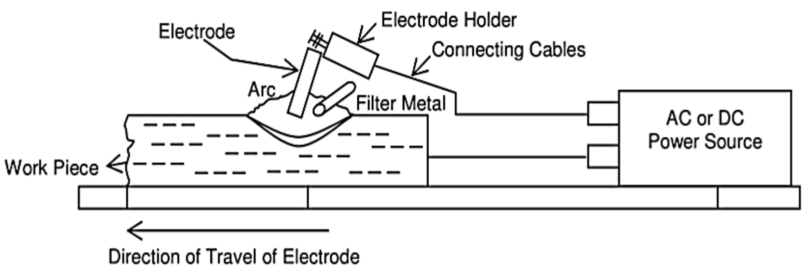
Introduction: Welding is the process of joining together two pieces of metal with the application of heat or pressure or both is applied and with or without added metal for formation of metallic bond.

Types of welding:



Arc Welding: Electric arc welding is one of the fusion welding processes in which coalescence of the metal is achieved by the heat from an electric arc between an electrode and workpiece.

- Electric arc is generated when electrode is brought into contact with the work and is then quickly separated by a short distance approximately 2 mm.
- In order to produce the arc, potential difference between the two electrodes should be sufficient to allow them to move across the air gap.



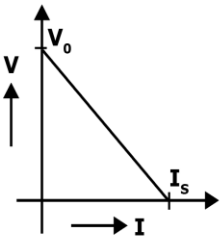
- The non-consumable electrodes made of tungsten or carbon. These do not melt in the process of welding and so called non-consumable electrodes.
- Consumable electrodes are consumed in the welding operation.

- In case of use of non-consumable electrode separate filler metal is used to improve properties of weldment. Selection of a filler metal depends on the metal to be welded.
- Flux gives alloys to bead materials, bead becomes stronger than parent metal. It protects the bead from atmospheric gases.

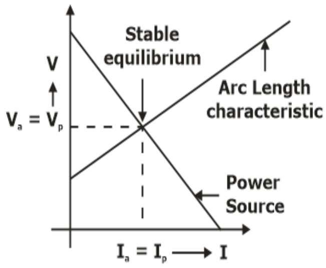
V-I characteristics of arc welding:

$$V = V_0 - V_{Drop}$$

$$\boxed{V = V_0 - \left(\frac{V_0}{I_S}\right)I}$$



V-I characteristic



$\boxed{V = a + bL}$ → arc length characteristics

Where L = Arc Length

At stable equilibrium condition:

$V_a = V$

Power $P = VI$

$$P = (a + bL)I = (a + bL)\left[\frac{I_S}{V_o}(V_0 - a - bL)\right]$$

For maximum power output:

$$\frac{dP}{dL} = 0 \rightarrow L = \text{...optimum arc length.}$$

$V_{opt} < V_o$

$I_{opt} < I_S$

Duty cycle: Duty cycle is the percentage of time that a machine will safely operate (or weld), within a certain time period, at a given amperage.

$$\boxed{\text{Duty Cycle} = \frac{\text{Arc on Time (AOT)}}{\text{Total welding Time}}}$$

Total welding time = Arc on time + Rest

Time For a welding transformer

$$\boxed{I_d^2 D_d = I_r^2 D_r}$$

Where

I_d = Desired output current in Amp

I_r = Rated output current in Amp

D_d = Desired duty Cycle %

D_r = Rated duty Cycle%

Hear flow characteristics in Arc Welding:

Heat input rate: Q = KVI

$$\text{No of electrodes required / pass} = \frac{\text{Length of weld head}}{x}$$

$$\text{Number of passes} = \frac{\text{Total number of electrodes required}}{\text{Number of electrodes/pass}}$$

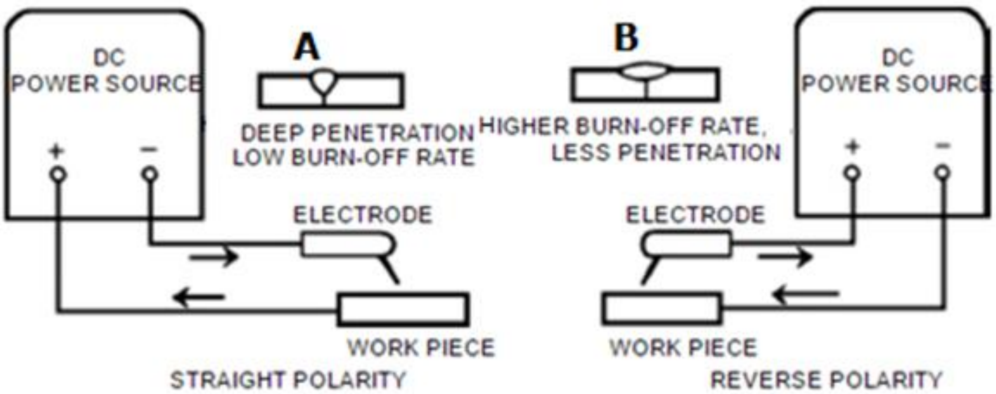
$$\text{Arc on time / pass} = \frac{\text{Length of weld head}}{\text{welding speed}}$$

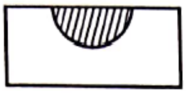
Total Arc on Time = A.O.T/pass × No of passes

$$\text{Total welding time} = \frac{\text{Time Arc on Time}}{\text{Duty cycle}}$$

Comparison of Different Electrode polarities:

DCRP and DCSP:



	Direct Current Straight Polarity **(DCSP)**	Direct Current Reverse Polarity **(DCRP)**	**ACHF**
1. Penetration	 shallow	 Deep	 Intermediate
2. Heat generation	2/3rd at electrode, 1/3rd at workpiece	1/3rd at electrode, 2/3 at workpiece	50% on both
3. Metal deposition rate	High	Low	Intermediate
4. Thickness of work to be welded	Thin sheets	Thick sheets	Intermediate
5. Stable smaller arc	Easier	Easier	Difficult
6. Arc blow	Severe	Severe	Insignificant

(a). Gas tungsten arc welding (GTAW) or TIG Welding:

- In a TIG welding process, ***a high intense arc is produced between non consumable tungsten electrode*** and work piece. Typical shielding gases include ***argon, helium, or a mixture of these gas elements***.
- A separate filler metal rod is used to deposit the material
- This was primarily invented to weld alloys of Aluminium and Magnesium. Aluminium is very difficult to weld because as soon as it is exposed to atmosphere it forms a layer over it. To weld these materials work piece should be given negative polarity and electrode positive polarity.

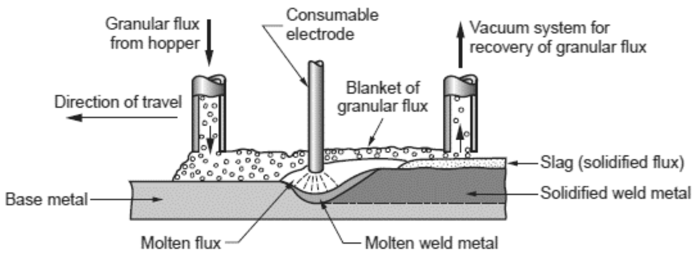
(b). Gas Metal arc welding (GMAW) or MIG Welding: The electrode is a ***consumable bare metal wire***, and shielding is accomplished by flooding the arc with Gases such as ***argon and helium, and active gases such as carbon dioxide***. The bare wire is fed continuously and automatically from a spool through the welding gun.

Inert gases are used for welding aluminium alloys and stainless steels, while CO_2 is commonly used for welding low and medium carbon steels. GMAW is widely used in fabrication operations in factories for welding a variety of ferrous and nonferrous metals

(c). Shielded Metal arc welding (SMAW) or stick welding: It uses a consumable electrode consisting of a filler metal rod coated with chemicals that provide flux and shielding. Currents typically used in SMAW range between 30 and 300 A at voltages from 15 to 45 V.

Shielded metal arc welding is usually performed manually. Common applications include construction, pipelines, machinery structures, shipbuilding, job shop fabrication, and repair work.

(d). Submerged Arc Welding (SAW): an arcwelding process that uses a continuous, consumable bare wire electrode, and arc shielding is provided by a cover of granular flux. The Submerged Arc Welding can be used to weld pressure vessels like boilers.



Submerged arc welding is widely used in steel fabrication for structural shapes (e.g., welded I-beams); longitudinal and circumferential seams for large diameter pipes, tanks, and pressure vessels; and welded components for heavy machinery.

Low-carbon, low-alloy, and stainless steels can be readily welded by SAW; but not high-carbon steels, tool steels, and most nonferrous metals. Because of the gravity feed of the granular flux, the ***parts must always be in a horizontal orientation***.

(e). Electro gas welding: an AW process that uses a continuous consumable electrode (either flux-cored wire or bare wire with externally supplied shielding gases) and molding shoes to contain the molten metal. The process is primarily applied to vertical butt welding.

Principal applications of electro gas welding are steels (low-and medium-carbon, low-alloy, and certain stainless steels) in the construction of large storage tanks and in ship building.

(f). Plasma Arc Welding (PAW): A special form of gas tungsten arc welding in which a constricted plasma arc is directed at the weld area.

Argon, argon–hydrogen, and helium are also used as the arc-shielding gases. Plasma is the pool of ionized gas. Temperature is about 17000 $^{\circ}C$.

The process can be used to weld almost any metal, including tungsten. Difficult-to-weld metals with PAW include bronze, cast irons, lead, and magnesium.

(g). Carbon arc welding (CAW): is an arc-welding process in which a non-consumable carbon (graphite) electrode is used. The carbon arc process is used as a heat source for brazing and for repairing iron castings. It can also be used in some applications for depositing wear resistant materials on surfaces.

(h). Stud welding (SW) is a specialized AW process for joining studs or similar components to base parts. SW applications include threaded fasteners for attaching handles to cookware, heat radiation fi ns on machinery, and similar assembly situations.

Resistance Welding: The resistance welding is produced by means of electrical resistance across the two components to be joined.

Heat generated: $\boxed{H_g = I^2Rt}$

Where I = current passing through circuit

R = Electrical Resistance at the interface

t = time during which current is passing

Heat required for melting:

Heat Required: $\boxed{H_m = mL + mC_P(T_m - T_a)}$

Where: L = latent heat of fusion

T_m = Melting point of the material

T_a = ambient temperature

Melting efficiency (η_m) is given by:

$$\boxed{\eta_m = \frac{H_m}{H_g}}$$

For MIG welding:

Wire melting rate = filling rate of weld bead

$$\boxed{\frac{\pi}{4}d^2 \times f = A \times v}$$

Where f = feed rate of wire

d = diameter of the wire

A = area of the weld

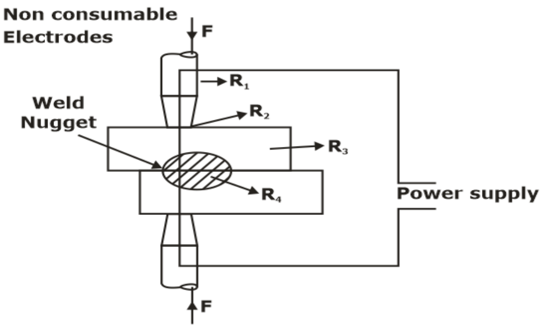
v = welding speed

Heat transfer efficiency (η_t) is given by:

$$\boxed{H_t = \frac{VI}{Av} \times \eta_t} J / mm^3$$

(a). Resistance Spot Welding: An RW process in which fusion of the faying surfaces of a lap joint is achieved at one location by opposing electrodes. The process is used to join sheet-metal parts of thickness 3 mm or less, using a series of spot welds, in situations where an airtight assembly is not required.

Materials used for RSW electrodes consist of two main groups: (1) copper-based alloys and (2) refractory metal compositions.



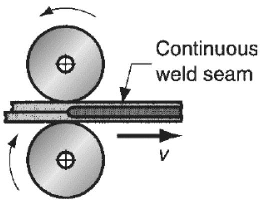
Volume of nugget: $\boxed{V = \frac{\pi}{4} D^2 h}$

Diameter of the nugget: $\boxed{D = 6\sqrt{t}}$ mm

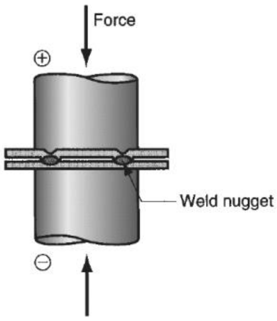
Press-type spot welders are intended for larger work than rocker arm type guns.

It is widely used in mass production of automobiles, appliances, metal furniture, and other products made of sheet metal.

(b). Seam Welding: Electrodes are in the form of rotating wheels and the welding is the Continuous spot welding. The current is applied through the heavy copper electrodes in a series of pulses at proper intervals. The process is capable of producing air-tight joints, and its industrial applications include the production of gasoline tanks, automobile mufflers.

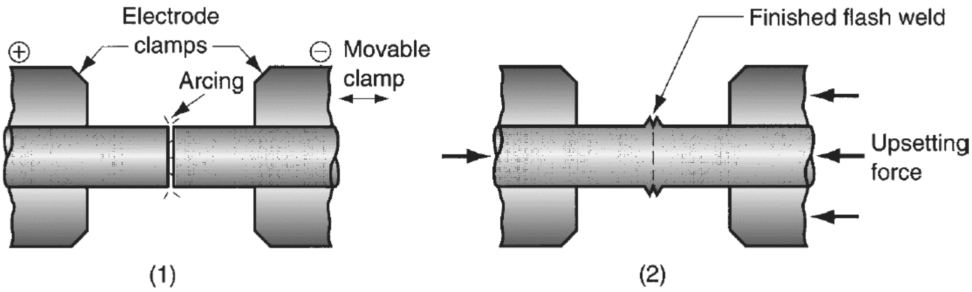


(c). Projection Welding: Resistance projection welding (RPW) is an RW process in which coalescence occurs at one or more relatively small contact points on the parts. The welding of two sheets without any indentation is done. One sheet has some projections.



(d). Other Resistance-Welding Operations:

(i). Flash butt Welding: In flash welding (FW), normally used for butt joints, the two surfaces to be joined are brought into contact or near contact and electric current is applied to heat the surfaces to the melting point, after which the surfaces are forced together to form the weld.

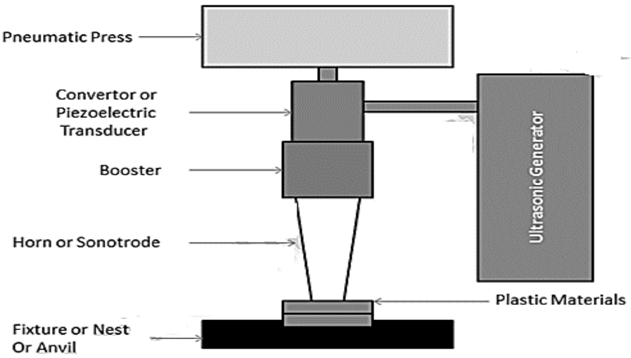


(ii). Upset welding (UW) is similar to flash welding except that in UW the faying surfaces are pressed together during heating and upsetting.

(iii). Percussion welding (PEW) is also similar to flash welding, except that the duration of the weld cycle is extremely short, typically lasting only 1 to 10 ms.

(iv). High-frequency resistance welding (HFRW) is a resistance-welding process in which a high-frequency (10 to 500 kHz) alternating current is used for heating, followed by the rapid application of an upsetting force to cause coalescence.

(v). Ultrasonic Welding (USW): It is a welding technique which uses ultrasonic vibration of high frequency to weld the two pieces together. It is most used to weld thermoplastic materials and dissimilar materials. Metal with thin section can also be welded with USW.



- The frequency applied is 20-60 KHz.
- It is a case of solid-state welding.

Electron beam welding (EBW): In this high velocity electron beam is made to strike at workpiece. ***High Vacuum is required*** and Entire set up is lead lines to avoid getting out of X rays. The electron beam gun operates at high voltage to accelerate the electrons (e.g., 10–150 kV typical), and beam currents are low (measured in milliamps). Welding speeds are high compared to other continuous welding operations. No filler metal is used, and no flux or shielding gases are needed. Minimum heat affected zone.

Any metals that can be arc welded can be welded by EBW, as well as certain refractory and difficult-to-weld metals that are not suited to AW. Work sizes range from thin foil to thick plate. EBW is applied mostly in the automotive, aerospace, and nuclear industries.

Laser beam welding (LBW): A fusion-welding process in which coalescence is achieved by the energy of a highly concentrated, coherent light beam focused on the joint to be welded. It is used to weld copper and aluminium alloys in electronics industry.

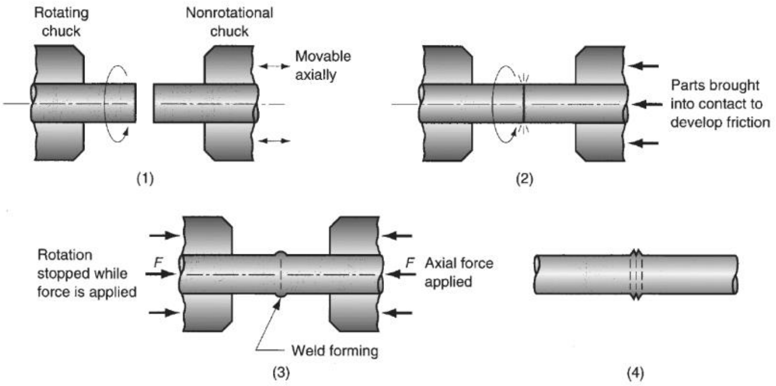
LBW produces welds of high quality, deep penetration, and narrow heat-affected zone. here are several advantages of LBW over EBW: no vacuum chamber is required, no X-rays are emitted, and laser beams can be focused and directed by optical lenses and mirrors.

Explosive welding: Explosion welding is solid state welding process where welding is accomplished by accelerating one of the components at extremely high velocity through the use of chemical explosives.

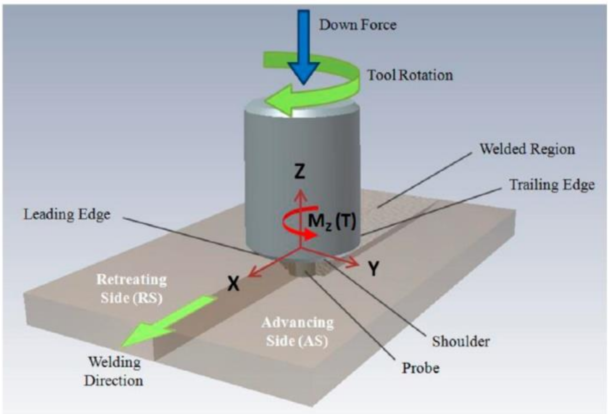
This process is most commonly utilized to clad carbon steel plate with a thin layer of corrosion resistant material.

Friction Welding: Friction welding (FRW) is a solid-state welding process in which coalescence is achieved by frictional heat combined with pressure. It is used for welding of dissimilar metals.

When properly carried out, no melting occurs at the faying surfaces. No filler metal, flux, or shielding gases are normally used.



Friction stir welding (FSW): Friction stir welding (FSW) is a solid-state joining process that uses frictional heat generated by a rotating tool to join materials. The process is primarily used in industry to join aluminium alloys of all grades, whether cast, rolled or extruded. FSW has been used for a variety of applications across industries ranging from aerospace to shipbuilding and rail to electronics, including EV battery trays.



Thermit Welding: Mixture of aluminium powder and iron oxide that produces an exothermic reaction when ignited. It is used in incendiary bombs and for welding. Mixture is placed in a crucible and ignited by means of a firecracker. It is used for repair of railway track.

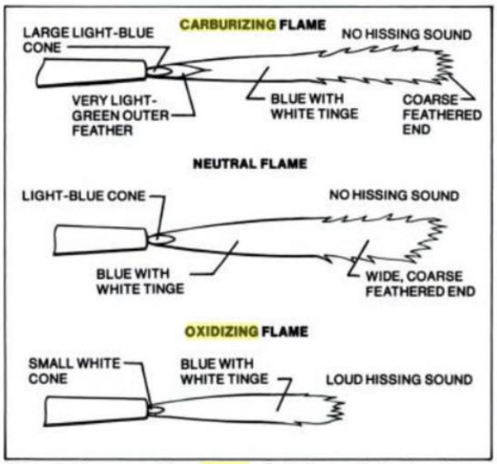
Finely mixed powders of aluminium and iron oxide (in a 1:3 mixture), when ignited at a temperature of around 1300°C, produce the following chemical reaction:

$8\ Al + 3\ Fe_3O_4$ ------> $9\ Fe + 4\ Al_2O_3$ + Heat

The temperature from the reaction is around 2500°C (4500°F), resulting in superheated molten iron plus aluminium oxide that floats to the top as a slag and protects the iron from the atmosphere.

GAS WELDING: Oxyfuel gas welding (OFW) is the term used to describe the group of FW operations that burn various fuels mixed with oxygen to perform welding. Oxyfuel gas is also commonly used in cutting torches to cut and separate metal plates and other parts. The most important OFW process is oxyacetylene welding.

Carburizing Flame: It has silent flame. This flame is obtained when excess of acetylene is supplied than which is theoretically required. It is used for cast iron. The inner cone has a feathery edge extending beyond it. This white feather is called the acetylene feather. Maximum temperature obtained is 3040°C.



Neutral Flame: This consists of nearly one to one ratio of acetylene and oxygen by volume. It is used for mild steel. Maximum temperature obtained is 3200°C.

Oxidizing Flame: Because of an excess amount of oxygen is supplied from the oxygen cylinder, distance to be travelled by the flame for complete combustion will be reducing, therefore, the length of inner cone is reduced. It produces roaring sound. It is used for copper zinc-based alloys. Maximum temperature obtained is 3380°C.

Soldering, Brazing:

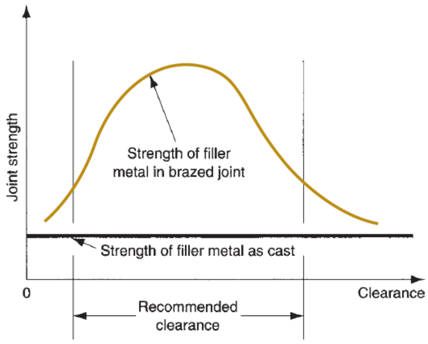
Soldering: A joining process in which a filler metal with melting point (liquidus) not exceeding 450°C is melted and distributed by capillary action between the faying surfaces of the metal parts being joined

The flux is zinc chloride.

The filler material is lead with tin.

Brazing: Brazing joints forms at temperatures higher than 450°C & the non-ferrous filler metal is drawn into and fills the closely fitted mating surface by capillary action. The joints obtained in Brazing are stronger than soldered joints.

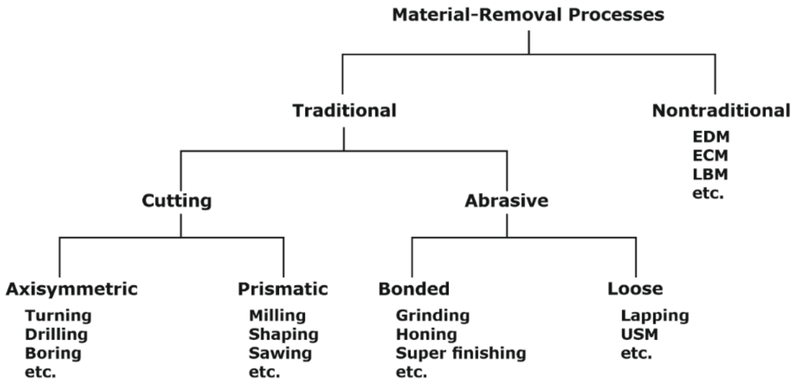
Common ingredients for brazing fluxes include borax, borates, fluorides, and chlorides.



Braze welding is different from Brazing & here the filler metal is deposited in groves & capillary attraction is not the factor in distributing the filler metal. Braze welding is frequently used to repair cracked or broken cast Iron parts.

CHAPTER 5: MACHINING AND MACHINABILITY

MACHINING: Machining is the process of removing unwanted material from workpiece. The important elements are workpiece, cutting tool, chips. Culling tools are classified into two major groups:



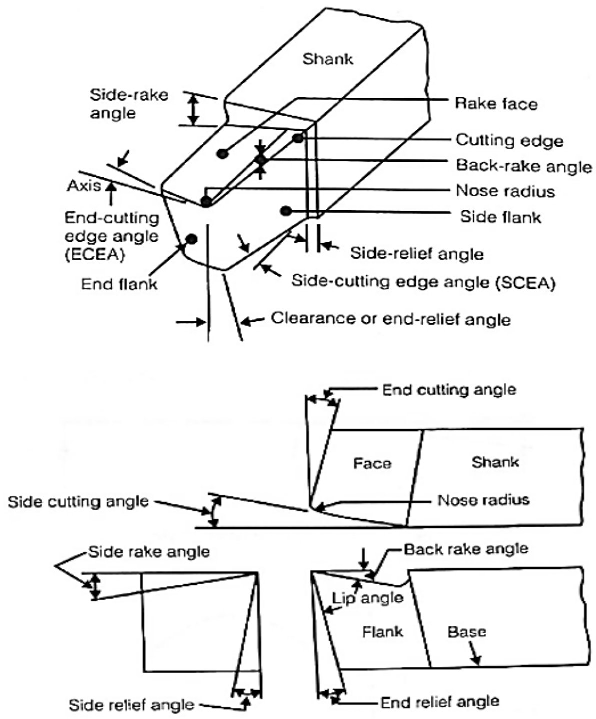
Single point cutting tools: In a single-point tool, there is one tool point from which the name of this cutting tool is derived. The point is usually rounded to a certain radius, called the nose radius.

Example: Turning tool, parting tool, Shaping tool etc.

Multipoint cutting tools: They have more than one cutting edge to remove excess material from the work piece.

Examples: Milling cutters, drills, reamers, broaches and grinding wheels are multi point cutting tools.

Single point cutting tool:



ASA Tool Signature:

Back rake angle - Side rake angle - End relief angle - Side relief angle - End cutting edge angle - Side cutting edge angle- Nose radius.

Orthogonal rake system (ORS):

Inclination angle-Normal Rake Angle - side relief angle- end relief angle - end cutting edge angle - approach angle λ – Nose Radius R.

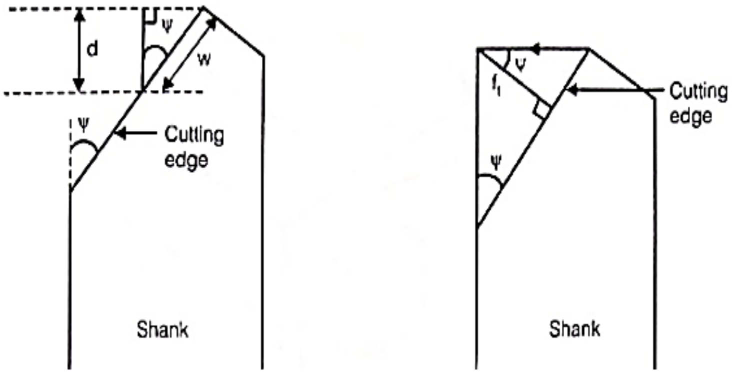
Conversion formulas from one system to other:

$$\begin{array}{|l|}\hline \tan I = \cos\Psi \tan\alpha_{ab} - \sin\Psi \tan\alpha_{as} \\ \tan\alpha_n = \cos\Psi \tan\alpha_{as} + \sin\Psi \tan\alpha_{ab} \\ \hline\end{array}$$

Where Ψ = side cutting edge angle

Back rake angle: For Machining brass, zero-degree rake angles are chosen.

Side cutting edge angle (Ψ):



$$\boxed{w = \frac{d}{\cos\Psi}}$$

d = depth of cut

w = width of cut

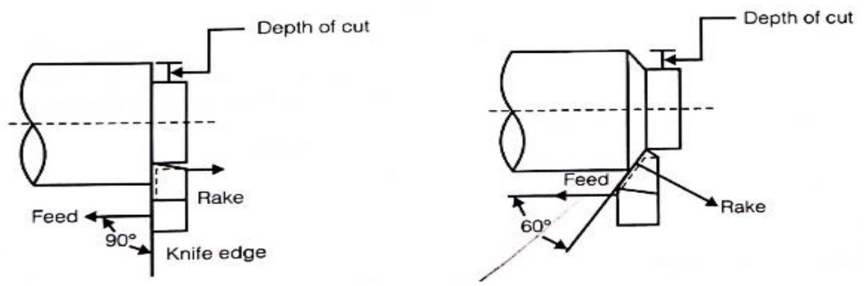
$$\frac{f_t}{f} = \cos\Psi$$

True feed: $\boxed{f_t = f\cos\Psi}$

t_1 = uncut chip thickness.

TYPES OF METAL CUTTING PROCESS:

Orthogonal cutting (Two-dimensional cutting). Cutting edge is at right angle to tool feed.



Oblique cutting (Three-dimensional cutting): Cutting edge is at acute angle to tool feed.

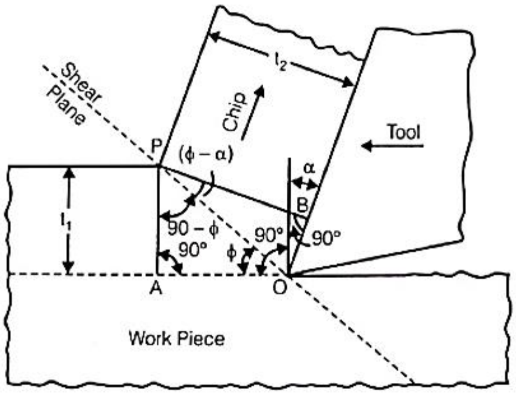
Types of chips:

Continuous Chips: Ductile materials, High speed, Low feed and depth of cut and High back rake angle.

Discontinuous Chips: Brittle materials, Low speed, High feed and depth of cut and Low back rake angle.

Chips with built-up edge: Ductile material, Low speed and High feed and depth of cut.

MERCHANT'S ANALYSIS:



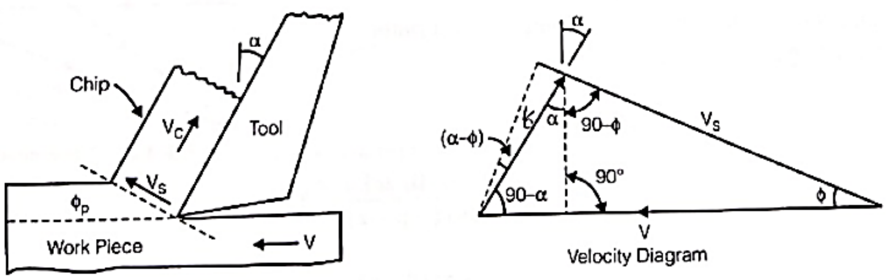
$$\boxed{\tan\phi = \frac{\cos\alpha}{\frac{t_2}{t_1} - \sin\alpha}}$$

chip thickness ratio: $\boxed{r = \frac{t_1}{t_2}} < 1$

$$\boxed{r = \frac{t}{t_c} = \frac{l_c}{l} = \frac{V_C}{V} = \frac{\sin\phi}{\cos(\phi - \alpha)}}$$

Chip reduction coefficient: $\boxed{\zeta = \frac{1}{r} = \frac{t_2}{t_1}} > 1$

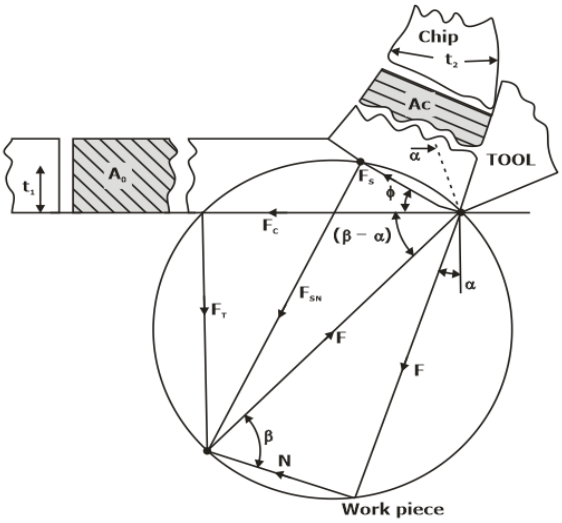
Shear strain: $\boxed{\gamma = \tan(\phi - \alpha) + \cot\phi}$



$$\frac{V}{\sin(90° - \phi + \alpha)} = \frac{V_C}{\sin\phi} = \frac{V_S}{\sin(90° - \alpha)}$$

$$\boxed{\frac{V}{\cos(\phi - \alpha)} = \frac{V_C}{\sin\phi} = \frac{V_S}{\cos\alpha}}$$

$$\boxed{V_S = \frac{V\cos\alpha}{\cos(\phi-\alpha)} \text{ and } V_c = \frac{V\sin\phi}{\cos(\phi-\alpha)}}$$



Resultant force: $\boxed{R = \sqrt{F_C^2 + F_T^2}}$ = Diameter of Merchant circle

$$\boxed{R = \frac{F}{\sin\beta} = \frac{N}{\cos\beta} = \frac{F_S}{\cos(\phi+\beta-\alpha)}}$$

Friction angle: $\boxed{\beta = \alpha + \tan^{-1}\left(\frac{F_T}{F_C}\right)}$

In general $F_C > F_T$, but in some cases $F_C < F_T$ like face turning operation, broaching, grinding etc

$$\boxed{\frac{F_T}{F_C} = 2.5(\text{Grinding})}$$

In that case According to Classical frictional theorem:

$$\boxed{\mu = \frac{\ln\left(\frac{1}{r}\right)}{\frac{\pi}{2} - \alpha}}$$

Shear plane area: A_s = AB × b

Where AB is the shear plane length.

$$\boxed{A_s = \frac{t_1}{\sin\phi} \times b}$$

$$\boxed{\text{W.D} = \text{Energy required} = F_C \times V_C}$$

Merchant's 1st angle relation (Minimum Power Requirement):

$$\boxed{2\phi + \beta - \alpha = 90^\circ}$$

Lee and Shaffer relation:

$$\boxed{\theta + \beta - \alpha = 45^\circ}$$

Machining constant or Merchants constant (C_m):

$\boxed{C_m = 2\phi + \beta - \alpha}$

SPECIFIC CUTTING ENERGY: $\boxed{SCE = \frac{\text{Work done}}{\text{material removal rate}}} \frac{J}{mm^3}$

Specific cutting pressure or specific cutting energy:

$\boxed{SCE = \frac{F_C \times V_C}{t_1 \times b \times V_C} = \frac{F_C}{A_0}}$ N/mm^2

TAYLOR'S TOOL LIFE EQUATION:

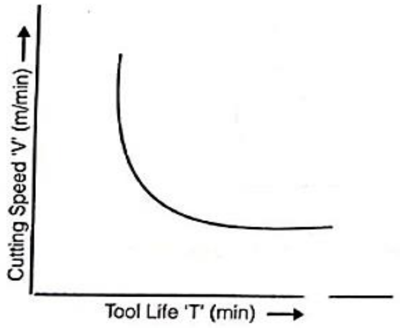
$\boxed{VT^n = C}$

V = cutting speed

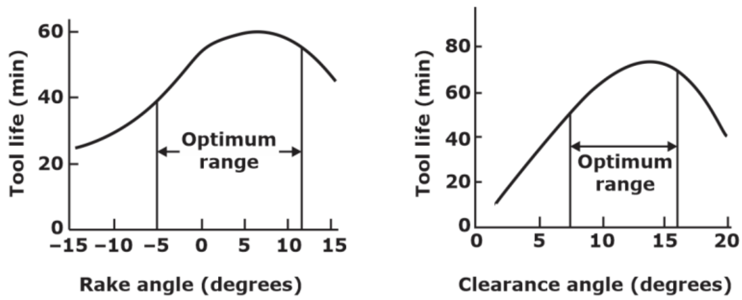
T = tool life.

C = machining constant.

n = Tool life exponent (depends only on tool material)



Effect of Back Rake angle on tool life:



(a) Effect of rake angle (b) Effect of clearance angle

When the rake angle increases, Life starts improving because the cutting force reduces. A further increase in the rake angle results in a larger temperature since the tool becomes thinner and the area available for heat conduction reduces.

Similarly, when the clearance angle increases, the tool life increases at first. This is due to for the same volume of flank wear, h_f reduces. However, with a further increase in the clearance angle, the tool becomes thinner and the tool life decreases due to the higher temperature.

Effect of parameters:

Higher the cutting speed tool life will decrease. By increasing the feed and depth of cut, tool life will decrease.

$$\text{Machinability index} = \frac{V_t}{V_s} \times 100$$

V_S = Cutting speed of standard free-cutting steel for 1 min tool life.

V_t = Cutting speed of metal for 1 min tool life.

Economics of machining:

Minimum Cost Criteria:

$$T_{opt} = \left[\left(\frac{1-n}{n}\right)\frac{C_t}{C_m}\right]$$

Maximum production rate criteria:

$$T_{opt} = \left[\left(\frac{1-n}{n}\right)T_c\right]$$

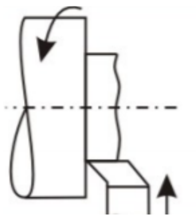
Velocity and Tool life order:

$$(V_{opt})_{min\ cost} < (V_{opt})_{max\ profit} < (V_{opt})_{max.\ prod.\ rate}$$

$$(T_{opt})_{max\ prod.\ rate} < (T_{opt})_{max\ profit} < (T_{opt})_{min\ cost}$$

Various Operation of Metal cutting:

Facing Operation:



$$\text{Time per cut} = \frac{\text{length of tool travel}}{\text{feed velocity}} = \frac{L}{fN}$$

$$L = \frac{D}{2} + AP + OR$$

Turning operation:

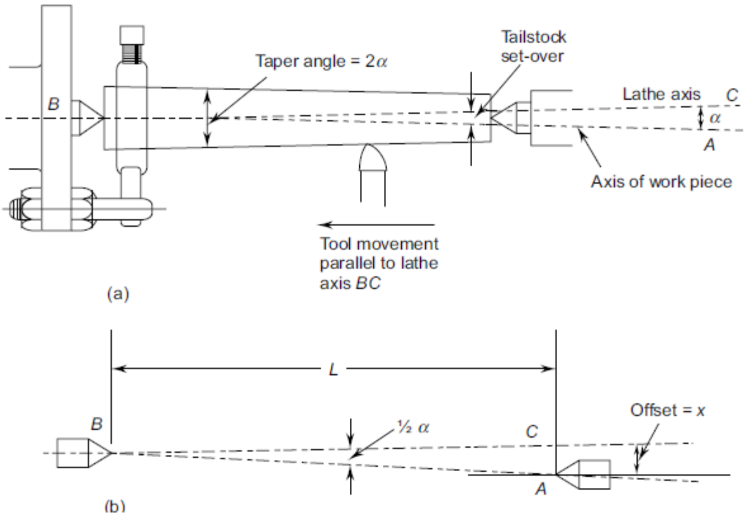
$$\text{Time per cut} = \frac{\text{length of tool travel}}{\text{feed velocity}} = \frac{L}{fN}$$

The empirical formula used for calculating the taper is:

$$\tan\theta = \frac{D_1 - D_2}{2L}$$

Where θ is half of the included angle, D_1 and D_2 are the major and minor diameters of the workpiece and L is the length of the tapered portion.

Offsetting the tailstock:



If α is very small, then we can approximate

$$\boxed{\sin\alpha = \tan\alpha = \frac{D-d}{2L}}$$

$\therefore$ Offset: $\boxed{S = L\frac{(D-d)}{2l} = \frac{(D-d)}{2}\times\frac{\text{Total length of workpiece}}{\text{Taper length}}}$

This is the most general situation where the taper is to be obtained over a small portion of the length (l) of the job while the actual length of the work piece, L could be long. However, when they are equal i.e. L = l, then:

Offset: $\boxed{S = \frac{(D-d)}{2}}$

In turning:

As depth of cut: $d = \frac{D_i - D_f}{2}$ and $V = \pi D_{avg} N$ mm / min

$$D_{avg} = \frac{D_i + D_f}{2} \Rightarrow V = \pi\frac{D_i + D_f}{2}N$$

Thus, $\boxed{MRR = \pi\left(\frac{D_i^2 - D_f^2}{4}\right)fN}$ mm^3/min

Thread cutting operation

Time/cut : $\boxed{t_m = \frac{L}{fN}}$

L = Length of the component + AP + OR

f = pitch → single start = lead → multi-starts

Lead = pitch × number of starts

Gear ratio = Train value = speed of follower/speed of driver

$$\boxed{\text{Gear ratio} = \frac{\text{number of teeth on driver gear}}{\text{number of teeth on driven gear}} = \frac{\text{pitch to be cut on job}}{\text{pitch on lead screw}}}$$

$$\boxed{\text{Gear ratio} = \frac{\text{Lead of job threads}}{\text{lead of lead screw threads}}}$$

Drilling:

Time/hole : $\boxed{t_m = \frac{L}{fN}}$

L = Length of tool travel

L = t + (AP_1) + AP + OR

Break through distance: $\boxed{A = \frac{D}{2\tan\alpha}}$

MRR in drilling: $\boxed{MRR = \frac{\pi}{4}D^2 fN}$

Broaching: Broaching is a method of removing metal by a tool that has successively higher cutting edges in a fixed path.

Knurling Process: Knurling is a manufacturing process, typically conducted on a lathe, whereby a pattern of straight, angled or crossed lines is rolled into the material to make a grip on the surface.

Thread Rolling: A work blank is pressed between either two flat dies or three circular die process and threads are produced plastic deformation process.

Boring: It is the process of enlarging already existing hole to bring it to the required size.

Reaming: It is the process of finishing the hole.

Counter Boring: Counterboring provides a stepped hole, in which a larger diameter follows a smaller diameter partially into the hole.

Counter sinking: This is similar to counterboring, except that the step in the hole is cone-shaped for flat head screws and bolts.

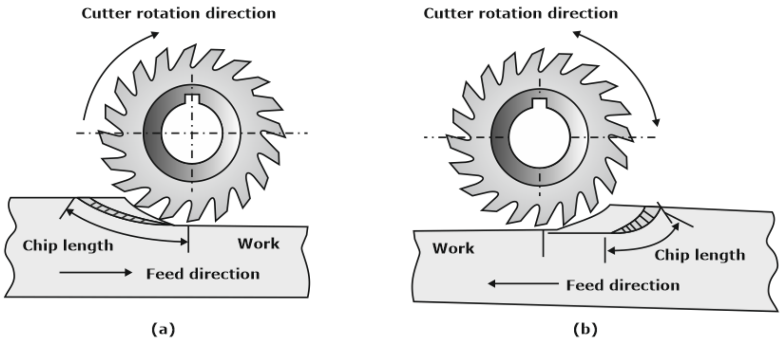
MILLING:

The material removal rate is:

$\boxed{MRR = w \times d \times f_m}$

Peripheral or slab milling operation: In peripheral milling, also called plain milling, the axis of the tool is parallel to the surface being machined.

Two forms of peripheral milling: In peripheral milling, the direction of cutter rotation distinguishes two forms of milling: up milling and down milling.



Two forms of peripheral milling operation Up milling or conventional milling

Up milling (conventional milling): the direction of motion of the cutter teeth is opposite the feed direction when the teeth cut into the work. the chip formed by each cutter tooth starts out very thin and increases in thickness during the sweep of the cutter.

Down Milling (Climb Milling): The direction of cutter motion is the same as the feed direction when the teeth cut the work. Each chip starts out thick and reduces in thickness throughout the cut.

$AP = O_1O_2$

$$\boxed{AP = \sqrt{Dd - d^2} = \sqrt{d(D - d)}}$$

Maximum chip thickness: $\boxed{t_{1max} = \frac{2f_m}{NZ}\sqrt{\frac{d}{D}}}$

Average chip thickness: $\boxed{t_{1avg} = \frac{f_m}{NZ}\sqrt{\frac{d}{D}}}$

f_m = Table speed or feed in mm/min

$f \times N = f_t \times Z \times N$

Feed per tooth: $\boxed{f_t = \frac{f_m}{NZ}}$

f = table feed in mm/rev

f_t = table feed in mm/tooth

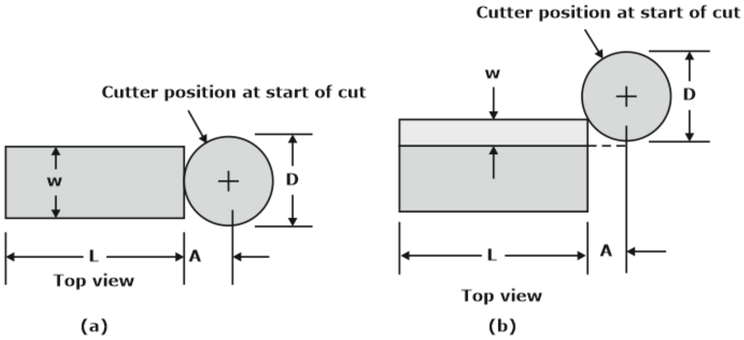
N = rpm of cutter

Z = Number of teeth

d = depth of cut

D = diameter of milling cutter

Face Milling: In face milling, the axis of the cutter is perpendicular to the surface being milled.



(a). When cutter is centered over the work piece and (b). When cutter is offset to one side over the work.

Symmetric milling: $\boxed{A = 0.5(D - \sqrt{D^2 - w^2})}$

If D = w, $\boxed{A = 0.5D}$

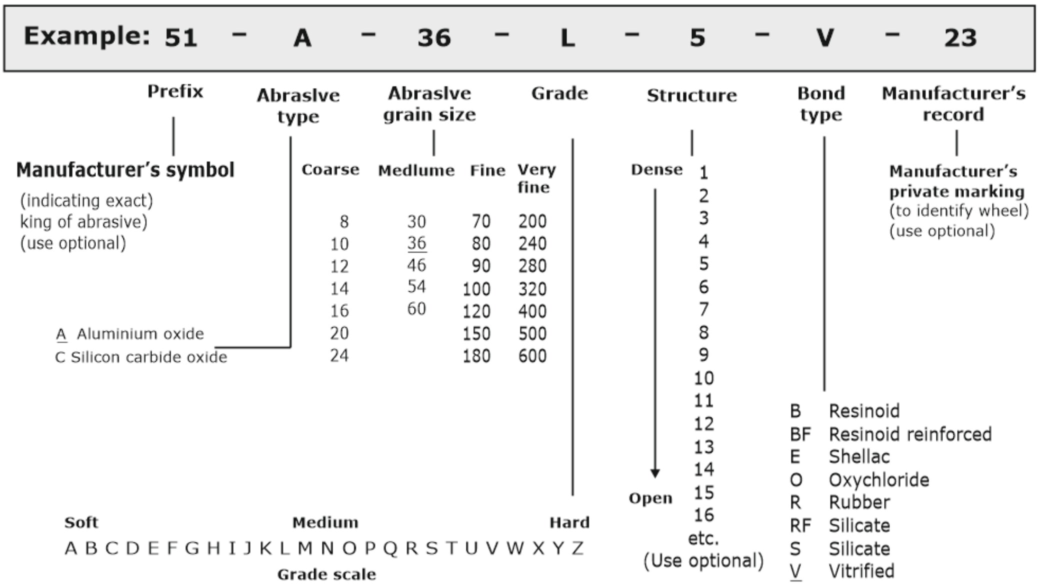
If D < w, then a slot is cut into the work and it = 0.5D.

When Cutter is offset: $\boxed{A = \sqrt{w(D - w)}}$

Grinding: Grinding is a chip-removal process that uses an individual abrasive grain as the cutting tool, and it is accomplished by abrasive particles that are contained in a bonded grinding wheel rotating at very high surface speeds.

Grinding Wheel Specification:

The preceding parameters can be concisely designated in a standard grinding wheel marking system defined by the American National Standards Institute (ANSI). This marking system uses numbers and letters to specify abrasive type, grit size, grade, structure, and bond material.



The undeformed chip length (l) in surface grinding is approximated by the equation

$\boxed{l = \sqrt{Dd}}$

The undeformed chip thickness, t, by the equation:

$$t = \sqrt{\left(\frac{4V}{VCr}\right)}\sqrt{\left(\frac{d}{D}\right)}$$

Grinding Ratio: Grinding-wheel wear is generally correlated with the amount of workpiece material ground by a parameter called the grinding ratio, G, defined as:

$$G = \frac{\text{volume of material removed}}{\text{Volume of wheel wear}}$$

External Centreless grinding: The following equation can be used to predict through feed rate, based on inclination angle and other parameters of the process:

$$f_r = \pi D_r N_r \text{Sin} I$$

Where:

f_r: through feed rate, mm/min

D_r: diameter of the regulating wheel, mm

N_r: rotational speed of the regulating wheel, rev/min

I: inclination angle of the regulating wheel

Honing: Honing is an abrasive process performed by a set of bonded abrasive sticks. A common application is to finish the bores of internal combustion engines. The motion of the honing tool is a combination of rotation and linear reciprocation, regulated in such a way that a given point on the abrasive stick does not trace the same path repeatedly. *Honing speeds are 15 to 150 m/min. Hone pressures of 1 to 3 MPa are typical.*

Lapping: Lapping is an abrasive process used to produce surface finishes of extreme accuracy and smoothness. Common abrasives are aluminium oxide and silicon carbide with typical grit sizes between 300 and 600.

NON -TRADITIONAL MACHINING:

Requirements: When material is very hard and strong which is difficult to machine by traditional process. When job is very complex.

(a). Electric Discharge Machining: The shape of the finished work surface is produced by a formed electrode tool.

(i). High voltage, low current process.

(ii). Mechanism of metal removal: Erosion, melting, vaporisation.

(iii). Dielectric is kerosene.

(iv). Energy released/spark: $E = \frac{1}{2} CV_d^2$ J

Cycle time : $t_c = RC \ln\left[\frac{V_0}{V_0 - V_d}\right]$ sec

Avg. power input: $P_{avg} = \frac{E}{t_c}$

The discharge voltage (V_d) and dc source voltage (V_o) relation is given by:

$$\boxed{V_d = V_o\left(1 - e^{-t_c/RC}\right)}$$

For maximum power delivery:

$$\boxed{\left(\frac{V_d}{V_o}\right)_{opt} = 0.72}$$

For a purely inductive discharging circuit, the critical value of resistance is:

$$\boxed{R_{min} = \sqrt{\frac{L}{C}}}$$

Where,

L = inductance of discharge circuit,

If R falls below this critical value, arcing, instead of sparking, will take place.

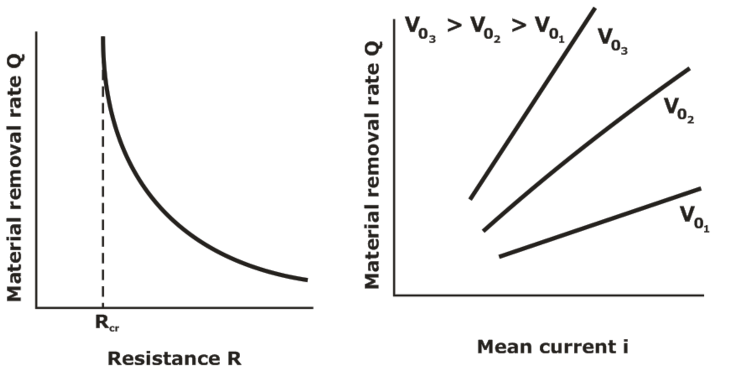
As in EDM, an overcut exists in wire EDM that makes the kerf larger than the wire diameter.

$$\boxed{MRR = \text{Cross section area of cut} \times \text{wire feed}}\left(mm^3 / sec\right)$$

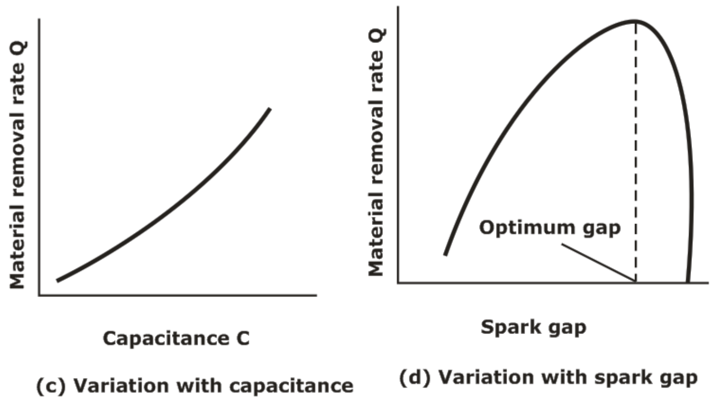
CSA of cut = width of cut × thickness of W/P

Width of cut = Wire diameter + Spark gap around the wire

MRR in the RC circuit:



(a) Variation with resistance (b) Variation with mean current



MRR characteristics in EDM using RC relaxation circuit

(b). Electro Chemical Machining (ECM):

- High current low voltage.
- Mechanics of MRR: Ion displacement
- Medium: Conducting electrolyte
- Tool Materials: Cu, Brass, Steel

$$\boxed{MRR = \left(\frac{AI}{ZF}\right)\frac{g}{sec} = \left(\frac{AI}{\rho ZF}\right)\frac{cm^3}{sec}}$$

F = Faraday's constant = 96,500 coleuses

I = current flowing in amperes

Z = Valences of metal dissolved

A=atomic wt of material in gms.

ρ = density of work piece, gm/cm^3

MRR for an alloy:

$$\boxed{Q = \frac{0.1035\times 10^{-2}}{\rho}\left(\frac{1}{\sum(x_i Z_i / A_i)}\right)}\ cm^3 / amp - sec$$

If the total overvoltage at the anode and the cathode be ΔV and the applied Voltage is V, the current I is given by:

$$\boxed{I = \frac{V - \Delta V}{R}}$$

Where R is ohmic resistance of the electrolyte.

Kinematics of ECM:

Current density = VK /y= ρ.f/Z

Where,

y = gap between tool and work,

V = applied voltage,

K = conductivity of electrolyte (mho/mm)

ρ = density of work material kg/mm 9

f = tool feed rate (mm/sec)

(c). Ultrasonic Machining (USM):

- **Mechanics of MRR:** Brittle fracture caused by impact of abrasive grains due to tool vibrating at high frequency.
- **Medium:** Slurry (abrasives mixed with water, paraffin etc.)
- **Abrasives:** Al_2O_3, B_4C (Boron Carbide), SiC, diamond (Usually B_4C with water as slurry and SiC with paraffin as slurry) and 100 — 800 grit size.
- Vibration frequency: 15 to 30 KHz
- Vibration Amplitude: 25 to 100 gm
- **Tool:** Material soft steel, cu or brass.
- For a given work material, the removal rate in USM:

$$\boxed{Q \propto \nu Z v}$$

Where:

Q = Volume of work material removal rate

v = frequency

Z = Number of particles making impact/cycle

v = volume of work material dislodged/impact

Shape Application: Round and irregular holes, impressions.

Limitations: Very low MRR, tool wear, depth of holes and small cavities

(d). Abrasive jet machining:

- Mechanism of material removal is due to brittle fracture by impinging abrasive grains at high speed.
- This process is more suitable when the work material is brittle and fragile.
- Media for flow of abrasives is air or CO_2, abrasive material is Al_2O_3 or SiC.

MRR in AJM:

Metal removal Rate in AJM is given by:

$$\boxed{MRR = \chi Z d^3 V^{1.5} \left(\frac{\rho}{12H_w}\right)^{3/4}}$$ Where,

χ = constant,

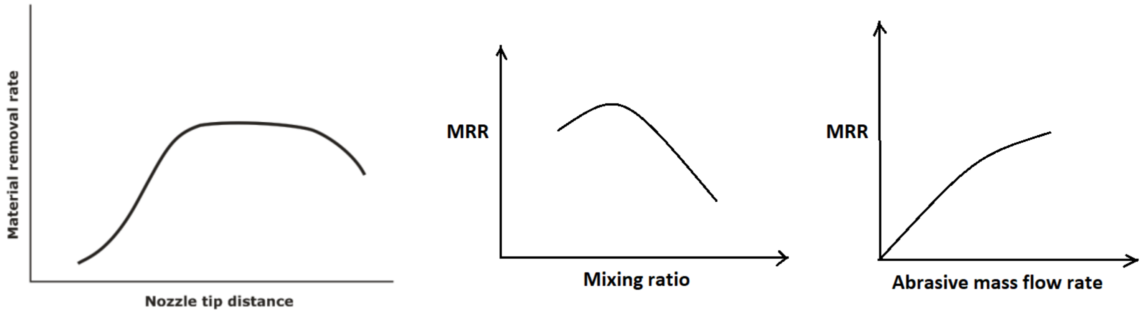
Z = no. of abrasive particles impinging per unit time

d = mean diameter of abrasive grains

V = velocity of abrasive grains

ρ = density of abrasive materials

H_W = hardness of work material



MRR Variation in AJM with different parameters

Shape Applications: Deburring, trimming and deflashing, cleaning, and polishing.

Materials Application: Cutting is accomplished successfully on hard, brittle materials (e.g., glass, silicon, mica, and ceramics) that are in the form of thin flat stock.

(e). Electron beam machining (EBM): It uses a high velocity stream of electrons focused on the workpiece surface to remove material by melting and vaporization. EBM must be carried out in a vacuum chamber to eliminate collision of the electrons with gas molecules.

The Total range to which electron can penetrate (δ) depends on the kinetic energy i.e. on the accelerating voltage V. It is given by:

$$\boxed{\delta = 2.6 \times 10^{-17} \frac{V^2}{\rho}}$$

Where:

δ = range in mm

V = the accelerating voltage in volts

ρ = density of the material in kg/mm^3

(f). Laser Beam Machining (LBM): It uses the light energy from a laser to remove **material by vaporization and ablation**. Ideal properties of a material for LBM include high light energy absorption, poor reflectivity, good thermal conductivity, low specific heat, low heat of fusion, and low heat of vaporization.

The time required to rise the surface to melting temperature is

$$\boxed{t_m = \frac{\pi}{\alpha}\left[\frac{\theta_m K}{2H}\right]^2}$$

α = thermal diffusivity = $\frac{K}{\rho C}$

K = thermal conductivity, J/m°C

H = heat flux = heat absorbed

θ_m = melting point temperature of work.

The critical value of 'H' is given by: $\boxed{H_{cr}\ \frac{2K\theta_m}{d}}$

Where:

d = focused diameter of incident beam.

If H = H_{cr}

Power intensity is the minimum value.

(g). Plasma Arc cutting (PAC): A plasma is a superheated, electrically ionized gas. Plasma arc cutting (PAC) uses a plasma stream operating at temperatures in the range 10,000°C to 14,000°C to cut metal by melting.

CHAPTER 6: METROLOGY AND INSPECTION

Introduction:

- **Fits:** Assembly condition between "Hole" & "Shaft".
- **Hole** – A feature engulfing a component
- **Shaft** – A feature being engulfed by a component.
- **Tolerance** is the difference between the upper limit (UL) and lower limit (LL).

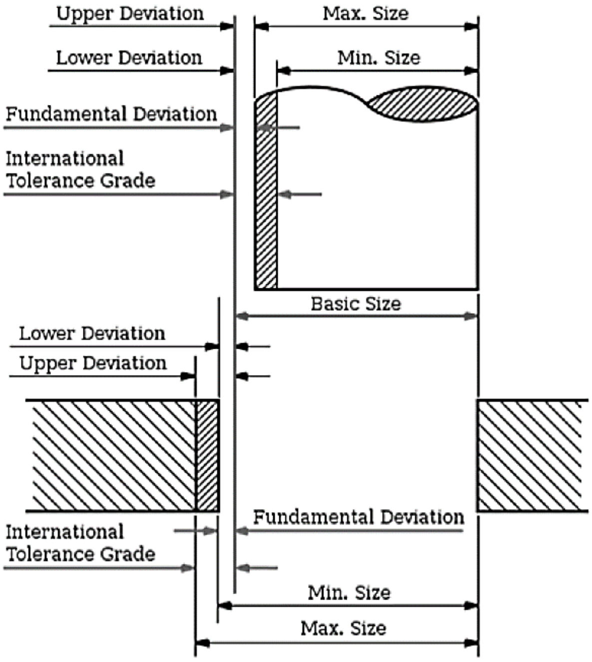
  $\boxed{\text{Tolerance} = UL - LL}$

- Limits of sizes are two extreme permissible sizes for a dimension of the part.

  Unilateral Limits i.e. only on one side of basic limit e.g. $\varnothing 25^{+0.18}_{+0.10}$

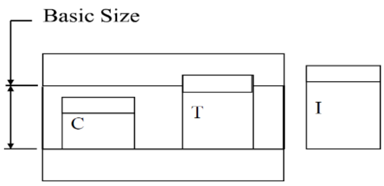
  Bilateral Limits i.e. on both sides of the basic size e.g. $\varnothing 25^{\pm 0.04}$

- **Upper deviation** is the algebraic difference between the maximum size and the basic size. The upper deviation of a hole is represented by a symbol ES (Ecart Superior) and of a shaft, it is represented by es.
- **Lower deviation** is the algebraic difference between the minimum size and the basic size. The lower deviation of a hole is represented by a symbol EI (Ecart Inferior) and of a shaft, it is represented by ei.
- Mean deviation is the arithmetical mean of upper and lower deviations.
- **Fundamental deviation** is the deviation, either the upper or the lower deviation, which is nearest one to zero line for a hole.



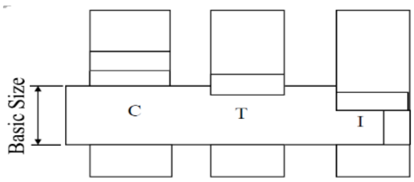
BASIS OF FITS:

Hole Basis: If the system of assembly of shaft and hole is consisting of basic hole, then that type of system is known as Hole Basis System.

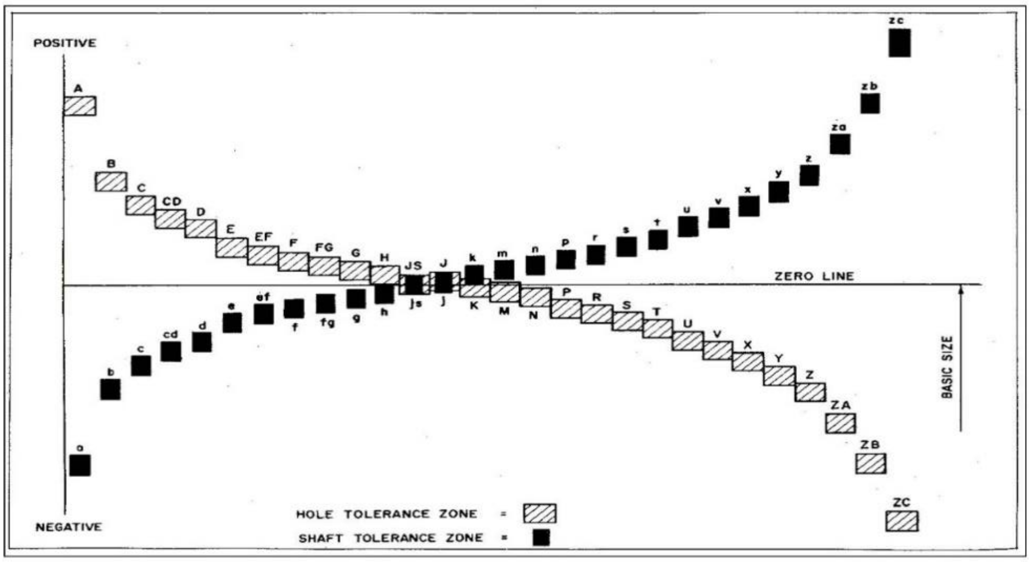


Hole Basis Fits

Shaft Basis: If the system of assembly of shaft and hole consisting of basic shaft, then that type of system is known as Shaft Basis System.



Shaft Basis Fits



IS: LIMITS AND FITS

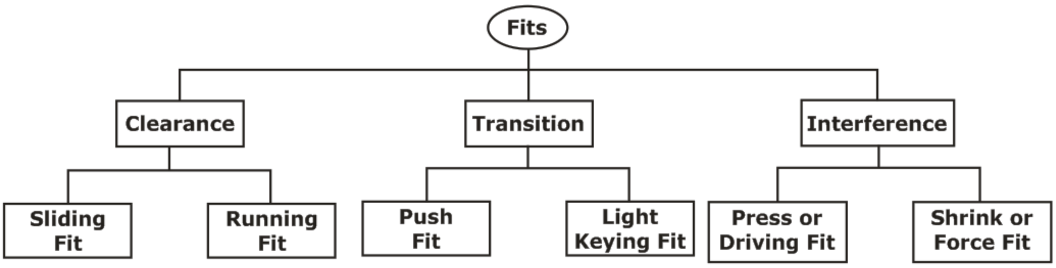
- Limits and fits comprise 18 grades of fundamental tolerances
- There are 25 types of fundamental deviations:

$$\boxed{i(\text{microns}) = 0.45\sqrt[3]{D} + 0.001\,D}$$

D is the size or geometric mean diameter in mm.

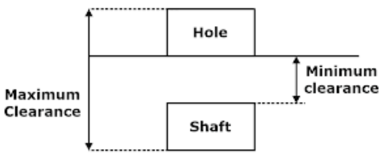
Tolerance grade	IT 5	IT6	IT7	IT8	IT9	IT10	IT11	IT12	IT13	IT14	IT15	IT16
Magnitude	7 i	10 i	16 i	25 i	40 i	64 i	100 i	160 I	250 i	400 i	640 i	1000 i

Fits: The condition which denotes the relationship between two mating parts with respect to the degree of clearance or interference appearing on the assembly is known as fit.



HOLE BASE & SHAFT BASE SYSTEM

(a). Clearance Fit: When lower limit of hole is greater than upper limit of shaft. Such fits give loose joint.

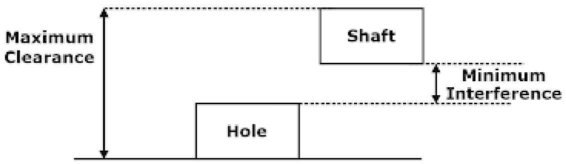


(i). Loose Fit: It is used between those mating parts where no precision is required. It provides minimum allowance and is used on loose pulleys, agricultural machineries etc.

(ii). Running Fit: For a running fit, the dimension of shaft should be smaller. For a running fit, the dimension of shaft should be smaller enough to maintain a film of oil for lubrication. It is used in bearing pair etc.

(iii). Slide Fit or Medium Fit: It is used on those mating parts where great precision is required. It provides medium allowance and is used in tool slides, slide valve, automobile parts, etc

(b). Interference fits: When lower limit of shaft is greater than upper limit of hole.



There are three types of interference fits namely: Shrink Fit or Heavy Force Fit, Medium Force Fit and Tight Fit or Force Fit.

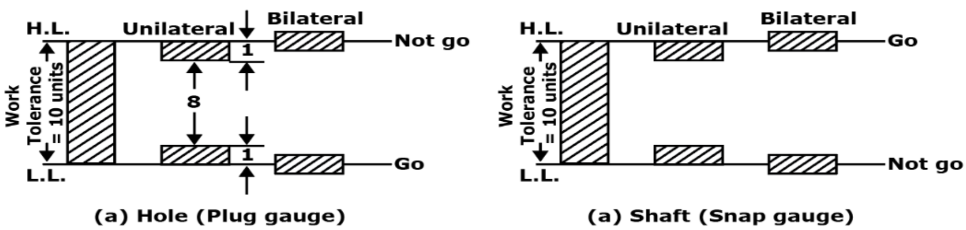
(c). Transition fit: When a part is selected randomly from whole lot and randomly from shaft lot, some of the assembly have clearance fit, some are having interference fit. This is called as transition fit.

There are three types of transition fits namely: Push Fit or Snug Fit, Force Fit or Shrink Fit and Wringing Fit.

Allowance: It is the difference between the basic dimensions of the mating parts. When the shaft size is less than the hole size, then the allowance is positive and when the shaft size is greater than the hole size, then the allowance is negative.

Unilateral system: In this system, the dimension of a part is allowed to vary only on one side of the basic size, i.e. tolerance lies wholly on one side of the basic size either above or below it.

Bilateral system: In this system, the dimension of the part is allowed to vary on both the sides of the basic size, i.e. the limits of tolerance lie on either side of the basic size.



Allocation of Manufacturing Tolerance

LIMIT GAUGES:

- **Plug gauge:** used to check the holes.
- **Snap, Gap or Ring gauge**: used for gauging the shaft and male components.

Wear allowance:

- GO gauges which constantly rub against the surface of the parts in the inspection are subjected to wear and loose their initial size.
- The size of go plug gauge is reduced while that of go snap gauge increases.

Gauge tolerance (GT) = $\frac{1}{10}$ (work tolerance)

Wear allowance = $\frac{1}{10}$ (gauge tolerance)= $\frac{1}{100}$ (work tolerance)

Wear tolerance is only provided where W.T ≥ 0.1 mm

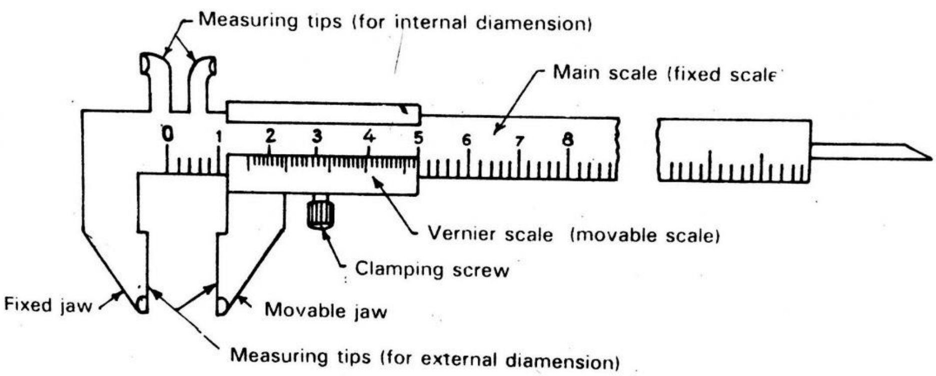
Slip gauges:

They are in the form of rectangular prisms, very accurately made in varying lengths. They are made of hardened steel having flat parallel surfaces. They are also called Gauge blocks.

Slip-gauge size of range, mm	Increment, mm	Number of pieces
1.005	-	1
1.001 to 1.009	0.001	9
1.010 to 1.490	0.010	49
0.500 to 9.500	0.500	19
10 to 100	10.000	10

One of the principles to be remembered is that the number of blocks used should always be the smallest.

Vernier Scale: A caliper is a device used to measure the distance between two opposing sides of an object. It can be as simple as a compass with inward or outward-facing points.



Least Count: The least count or the smallest reading which you can get with the instrument can be calculated as:

LC = 1 MSD – 1 VSD

$$\boxed{LC = \frac{1\ \text{MSD}}{\text{Number of divisions on vernier scale}}}$$

If the zero of the vernier scale lies ahead of the Nth division of the main scale, then the main scale reading (MSR) is:

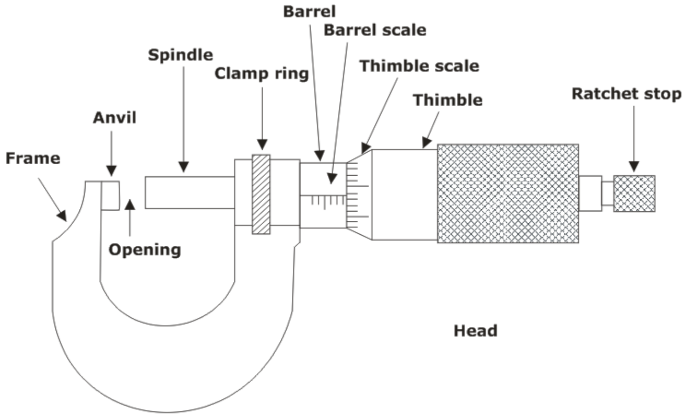
MSR = N

If nth division of Vernier scale coincides with any division of the main scale, then the Vernier scale reading (VSR) is:

VSR = n × LC

Total reading: $\boxed{TR = MSR + VSR = N + n \times LC}$

Micrometre: A micrometre, sometimes known as a micrometre screw gauge, is a device incorporating a calibrated screw widely used for accurate measurement of components. Micrometre screw gauge is an instrument used to measure the diameter of thin wires, the thickness of small sheets of glass, plastic, etc.



Least count of micrometer is given by:

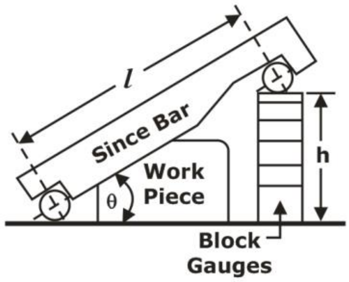
$$\boxed{LC = \frac{\text{Pitch of screw gauge}}{\text{Total number of divisions on circular scale}}}$$

Dial indicator: It Converts a linear displacement into a radial movement to measure over a small range of movement for the plunger.

Its application is direct measurement to be measured by the actual dimensions, and comparative measurement to read the amount of displacement from the phrase reference dimension.

Angular measurement devices:

(a). Sine bar: It is a simple instrument which can be easily used for setting and measuring angles. Fairly high accuracy can be expected when measuring smaller angles, that is less than 45°.



$\sin\theta = \frac{h}{l} \Rightarrow \boxed{\theta = \sin^{-1}\left(\frac{h}{l}\right)}$

(b). Bevel Protractor: It is part of the machinist's combination square. The flat base of the protractor helps in setting it firmly on the workpiece and then by rotating the rule, it is possible to measure the angle.

(c). Clinometer: A clinometer is a tool that is used to measure the angle of elevation, or angle from the ground, in a right - angled triangle. A Clinometer basically consists of a precision level mounted in a holder which is attached to a rotatable member.

(d). Autocollimator: An autocollimator is an optical instrument that is used to measure small angles with very high sensitivity. As such, the autocollimator has a wide variety of applications including precision alignment, detection of angular movement, verification of angle standards, and angular monitoring over long periods.

Straightness, Flatness and Squareness:

Straightness: It is defined as the deviation of surface from ideal straight line. This straightness can be measured in 3 ways.

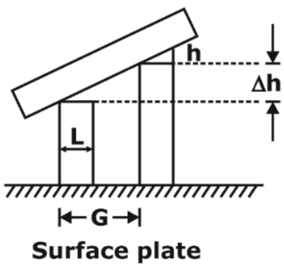
Spirit level: Surface under examination is divided into number of segments equal to the size of spirit level. Spirit level is there kept from one segment to another and position of bubble in it is noted down. The deviations of bubble form the center position are recorded.

Flatness: Flatness is defined as the departure of surface from ideal flat surface.

Interferometry:

Optical flat as comparator: Using optical flat difference is the size of slip gauge can be calculated from a master reference. Suppose the difference Δh has to be calculated:

From the similar triangles



Optical flat

$$\frac{h}{l} = \frac{\Delta h}{G}$$

$$\Rightarrow \Delta h = \left(\frac{h\lambda}{2}\right)\left(\frac{G}{L}\right)$$

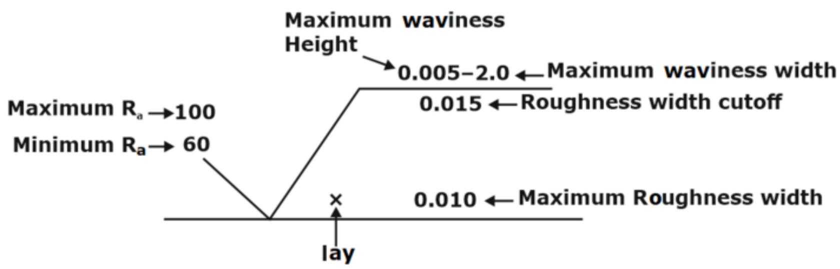
Surface Finish:

Roughness height: This is the parameter with which generally the surface finish is indicated. It is specified either as arithmetic average value or the root-mean-square value.

Roughness width: It is distance parallel to the nominal part surface within which lie the peaks and valleys, which constitute the predominant pattern of the roughness.

Roughness width cut-off: This is the maximum width of the surface that is included in the calculation of the roughness height.

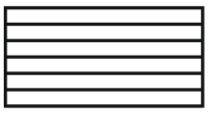
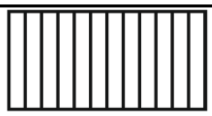
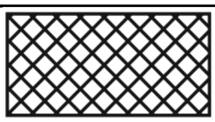
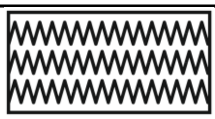
Waviness: Waviness refers to those surface irregularities that have a greater spacing than that of roughness width.



Standard terminology and symbols to describe surface finish

Example:

LAY DIRECTION: It is the direction of the predominant surface pattern produced on the workpiece by the tool marks. The different types of lays are as under

Symbol	Diagram	Description
=		**Parallel lay:** Surface is produced
⊥		**Perpendicular lay:** Surface is produced by shaping and planning
X		**Crossed lay:** Such surface can be produced by knurling operation
M		**Multidirectional lay:** Such surfaces are produced by grinding operation
C		**Circular lay:** The surfaces are produced by facing operation

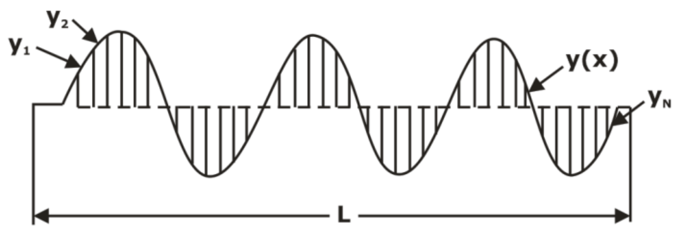
R		Radial lay

Types of lays

CENTER LINE AVERAGE VALUE (CLA, R_A):

If y=(f(x) is the characteristic equation of the roughness, R_a value can also be expressed as

$$\boxed{R_a = \frac{1}{L}\int_0^L |y(x)|\,dx \cong \frac{1}{N}\sum |y_i|}$$



Cutoff length is one in which measurement of roughness is being carried out (or length of travel of stylus). So, R_a value can also be represented as

$$R_a = \frac{\sum a + \sum b}{L}$$

Where ∑a = area above the line

∑b= area below the line

L= cutoff length

Root mean square roughness: $\boxed{R_{rms} \cong \sqrt{\frac{1}{N}\sum y_i^2}}$

PEAK TO VALLEY HEIGHT (R_T OR R_{MAX}): It is the difference between highest peak and deepest valley.

$$\boxed{R_a = \frac{H_{max}}{4}}$$

In case of turning operation when the nose radius (R) and the feed rate (f) is given Maximum height of unevenness can also be expressed as:

$$H_{\max} = \frac{f^2}{8R}$$

If complete tool signature is given, the peak to valley height can also be calculated as

$$H_{\max} = \frac{f}{\tan\psi + \cot\psi_1}$$

Where

f= feed rate

ψ =side cutting edge angle

ψ_1 =end cutting edge angle

CHAPTER 7: COMPUTER INTEGRATED MANUFACTURING

CIM: A computer is a machine that can be instructed to carry out sequence of arithmetic or logical operation automatically via computer programming.

CIM is the technique of using computers to control an entire production process. It's commonly used by factories to automate functions such as analysis, cost accounting, design, distribution, inventory control, planning and purchasing.

These functions are often linked to a central, computer-controlled station to enable efficient materials handling and management, while delivering direct control and monitoring of all operations simultaneously.

Methodology CAD/CAM: To use technical data from a database in the design and production stages. Information on parts, materials, tools, and machines are integrated.

CAD (Computer Aided Design): Allows the design in a computer environment.

CAM (Computer Aided Manufacturing): To manage programs and production stages on a computer.

Evolution of Numerical Control:

(i). Numerical Control (NC): Data on paper or received in serial port**,** NC machine unable to perform computations **and** Hardware interpolation.

(ii). Direct Numerical Control (DNC): Central computer control a number of machines DNC or CNC**.**

(iii). Computer Numerical control (CNC): A computer is on the core of each machine tool**,** Computation and interpolation algorithms run on the machine.

(iv). Distributive numerical control: scheduling**,** Quality control **and** Remote monitoring.

Solid modelling:

Wire frame Geometric modelling:

- 2-D Two-dimensional representation is used for a flat object.
- $2\frac{1}{2}$D : It allows somewhat beyond 2D capability by permitting a 3-D object to be represented if it has no side wall details.
- 3-D allows for full three-dimensional modelling of a more complex geometry.
- The most advanced method of Geometric modelling in 3-D is solid modeling.

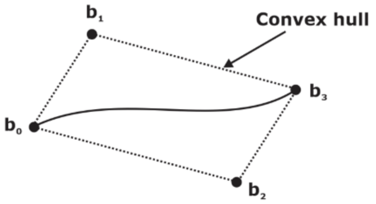
Bezier Curve:

- A parameter Bezier curve segment is a weighted sum of (n + 1) control points P_0, P_1, P_2, …., P_N

$$P(t) = \sum_{i=0}^{n} P_i B_{i,n}(t)$$

Where, $B_{i,n}$ (t) = Bezier blending function

- The Blending function is always a polynomial one degree less than the no. of control point.
- Bezier as convex hull of its control points.



- A Bezier curve of order (n+1) [degree n] has (n+1) control points.
- Bezier curves are widely used in computer graphics to model smooth curves.

Coon's Patch:

- A Coons patch is a bicubic parametric surface formed by four corner points, eight tangent vectors (two vectors in the u and w directions, respectively, at each of the four corners), and four twister vectors at the respective four corner points.

NURBS:

- It stands for the Non uniform rational basis spline. It is a mathematical model commonly used in computer graphics for generating and representing curves and surfaces.
- It offers a greater flexibility NURBS and precision for handling both the analytical and modeled shapes.
- NURBS is flexible for designers, designing a large variety of shapes by manipulating the control points and the weightages.
- Weights in the NURBS data structure determine the amount of surface deflection towards or away from its control points.

Transformation of geometry:

1. Translation:

Any graphical entity can be translated or moved in X or Y direction by using this routine. Basic equations used in this subroutine are:

$X' = X + T_X$

$Y' = Y + T_y$

(X ′, Y ′) are the new coordinates after translation and (X, Y) are the old coordinates before translation. T_x and T_y are the distance to be translated in x and y direction respectively.

The equations can be written in matrix form as

$$\begin{bmatrix} X' & Y' & 1 \end{bmatrix} = \begin{bmatrix} X & Y & 1 \end{bmatrix} \times \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ T_x & T_y & 1 \end{bmatrix}$$

Here matrix $\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ T_x & T_y & 1 \end{bmatrix}$ is called the translation matrix.

In 3D transformations, the x, y and z coordinates of a point are considered. For translation, the transformation matrix $[R_T]$ is given by:

$$[R_T] = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ T_x & T_y & T_z & 1 \end{bmatrix}$$

T_x, T_y, T_z being translation in x, y and z. directions respectively.

2. Scaling: This routine is used to enlarge the object or make it small. The basic equations are:

$X' = X.\ S_x$

$Y' = Y.\ S_y$

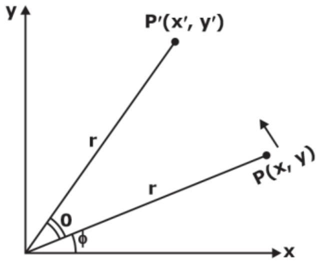
where S_x and S_y are the scaling factor in x and y direction, respectively.

$$\boxed{\begin{bmatrix} X' & Y' & 1 \end{bmatrix} = \begin{bmatrix} X & Y & 1 \end{bmatrix} \begin{bmatrix} S_x & 0 & 0 \\ 0 & S_y & 0 \\ 0 & 0 & 1 \end{bmatrix}}$$

For 3-D scaling, the transformation matrix is given by: $[R_S] = \begin{bmatrix} S_x & 0 & 0 & 0 \\ 0 & S_y & 0 & 0 \\ 0 & 0 & S_z & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

where S_x, S_y and S_z are scaling factors in x, y and z direction respectively.

3. Rotation: Rotation of any point is effective with respect to some fixed point. We assume anticlockwise rotation as positive and clockwise rotation as negative.



From the figure:

$X = r \cos \phi$ and $Y = r \sin \phi$

$X' = r \cos(\theta + \phi)$ and $Y' = r \sin(\theta + \phi)$

$$\boxed{\begin{bmatrix} X' & Y' & 1 \end{bmatrix} = \begin{bmatrix} X & Y & 1 \end{bmatrix} \begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}}$$

Rotation in 3-D can be about x, y or z axis. These equations of rotation of a point about z-axis is:

Rotation about Z-axis: $[R_z] = \begin{bmatrix} \cos\theta & \sin\theta & 0 & 0 \\ -\sin\theta & \cos\theta & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

Rotation about X-axis: $[R_x] = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta & \sin\theta & 0 \\ 0 & -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

Rotation about Y-axis: $[R_y] = \begin{bmatrix} \cos\theta & 0 & -\sin\theta & 0 \\ 0 & 1 & 0 & 0 \\ \sin\theta & 0 & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

4. Reflection:

(i). Reflection of X-axis (Y = 0 axis): Reflection matrix is given by:

$$[R_x] = \begin{bmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

After reflection, coordinates are (x′, y′) then:

$$\boxed{[X' \quad Y' \quad 1] = [X \quad Y \quad 1] \times [R_x]}$$

(ii). Reflection of Y-axis (X = 0 axis): Reflection matrix is given by:

$$[R_Y] = \begin{bmatrix} -1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Hence to find coordinates of point P' i.e. (x', y′) after reflection about y-axis:

$$\boxed{[X' \quad Y' \quad 1] = [X \quad Y \quad 1] \times [R_Y]}$$

(iii). To Find Reflection Matrix when the Axis of Reflection is the Line Passing Through origin (Y = X):

$$[R_{x=Y}] = \begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Hence to find coordinates of point P' i.e. (x', y′) after reflection about X= Y-axis:

$$\boxed{[X' \quad Y' \quad 1] = [X \quad Y \quad 1] \times [R_{X=Y}]}$$

(iv). To Find Reflection Matrix when the Axis of Reflection is the Line Passing Through origin (Y = - X):

$$\left[R_{x=-Y}\right]=\begin{bmatrix}0 & -1 & 0\\ -1 & 0 & 0\\ 0 & 0 & 1\end{bmatrix}$$

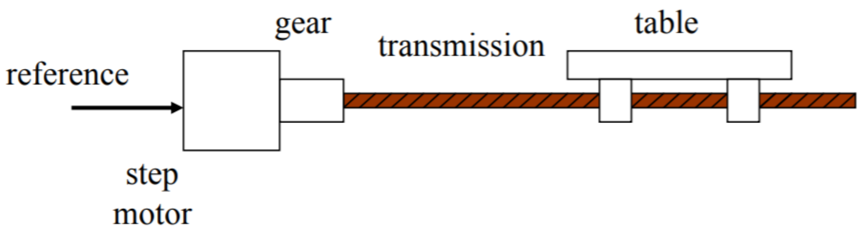
Hence to find coordinates of point P' i.e. (x', y') after reflection about X= - Y axis:

$$\boxed{\left[X' \quad Y' \quad 1\right]=\left[X \quad Y \quad 1\right]\times\left[R_{X=-Y}\right]}$$

Numerical control:

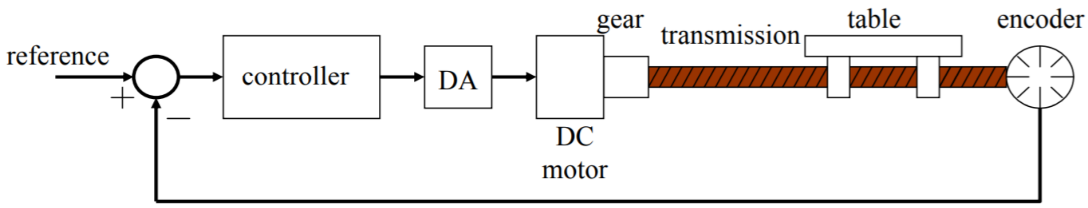
Open systems: The open loop system means the output of the system is free from their input due to being the non-feedback system. The open loop system is more stable as compared to a closed loop system. The open loop system gives the fast response.

Examples: The traffic light, automatic washing machine, etc. are the examples of the output system.

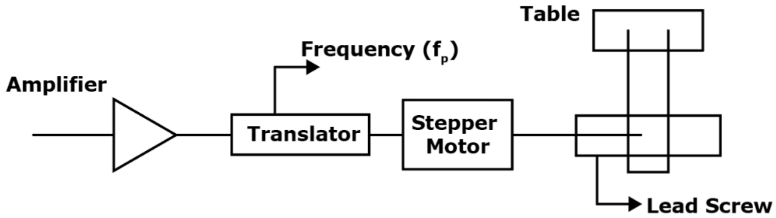


Closed system: In the closed-loop system, the desired output depends on their input due to being the feedback system. The construction of the closed-loop system is quite difficult. closed-loop system is reliable, and the accuracy of the system is more as compared to open loop system.

Example: The temperature controller, toaster etc. are the examples of the closed-loop system.



BASIC LENGTH UNIT(BLU): BLU is the distance moved by table corresponding to single pulse.



n_S = No. of steps

$$\boxed{\text{Step angle}=\frac{360^\circ}{n_S}}$$

$$\boxed{BLU = \frac{\text{Lead screw pitch}(mm)}{\text{Steps per revolution of stepper motor}}}$$

t = time period of pulse coming to stepper motor

f_P = frequency

Total pulse = $f_P \times t$

$$\text{Total angle} = \frac{360°}{n_S} \times f_p t$$

So, $\boxed{\text{No. of revolutions} = \frac{360° \times f_p t}{n_S \times 360°} = \frac{f_p t}{n_S} \text{rps}}$ $\boxed{N = \frac{60 f_p t}{n_S}}$

Also, linear velocity of stepper motor, V is given by the expression:

$\boxed{V = \text{pulse frequency x BLU x 60 mm / min}}$

PART PROGRAMING CODES:

G and M Codes:

G codes	Interpretation	M codes	Interpretation
G00	rapid traverse	M00	Programs stop
G01	linear interpolation	M01	Planned stop
G02	circular interpolation (CW)	M02	end of program
G03	circular interpolation (CCW)	M03	CW spindle rotation
G04	Dwell	M04	CCW spindle rotation
G05	Hold	M05	spindle off
G08	For acceleration	M06	Tool change
G09	For Retardation	M07, 08	Coolant on
G17	XY plane selection	M09	Coolant off
G18	YZ plane selection	M10	Clamp
G19	ZX plane selection	M11	unclamp
G33	thread cutting constant lead	M17	end of sub program
G34	thread cutting with increasing lead	M30	end of sub of main program
G35	thread cutting with decreasing lead		
G41	Tool radius compensation left		
G42	Tool radius compensation Right		
G63	Tapping		
G70	English programming		
G71	Metric programming		
G90	Absolute Positioning		

G91	Incremental positioning		

Other important codes for programming:

Symbol	Interpretation
N	Sequence Number or block number
G	Preparatory Function
X	X Axis Command
Y	Y Axis Command
Z	Z Axis Command
R	Radius from specified center
A	Angle ccw from +X vector
I	X axis arc center offset
J	Y axis arc center offset
K	Z axis arc center offset
F	Feed rate
S	Spindle speed
T	Tool Number
M	Miscellaneous function

NC Words order:

N _ _ G _ _ X _ _ Y _ _ Z _ _ f _ _ S _ _ T _ _ M _ _

It is the sequence of the words which will be followed while writing a block of the program.

Note:

- It is generally possible to include more than one G- address in a block, provided these functions are mutually exclusive.
- G02 and G03 together in one block are not permissible. If they are given, the latter i.e. G03 will become operational overriding the earlier of same category.
- Model G-codes behave as settings to the control.
- T01: tool designation represents the first tool used in the CNC program. T02: tool designation represents any tool in the CNC program between the first and last tool. T03: Tool designation represents the last tool used in the CNC program.
- T99: Tool designation represents empty tool (dummy tool) as an empty tool pocket identification.

Interpolator:

- Interpolator in a CNC machine coordinates axes movements.
- An interpolator determines the velocities of individual axis to drive the tool along the programmed path at given feed rate.
- It also provides intermediate coordinate positions along the programmed path.

Advanced CNC programming languages

- Automatically Program Tool (APT) Developed at MIT in 1954. Derived from APT:

(i). ADAPT (IBM)

(ii). IFAPT (France)

(iii). MINIAPT (Germany)

APT Language: APT is not only an NC language, it is an computer program that performs the calculations to generate cutter positions based on the APT statements.

Four type of statements in APT Language:

(a). Geometry statements

(b). Motion statements:

Point to point motions: Only two basic PTP motion commands: GOTO and GODLTA. The GOTO statement instructs the tool to go to a particular location specified in the descriptive data. The GODLTA command specifies an incremental move for the tool.

(c). Postprocessor statements

(d). Auxiliary statements

- Compact II
- Autospot
- SPLIT

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